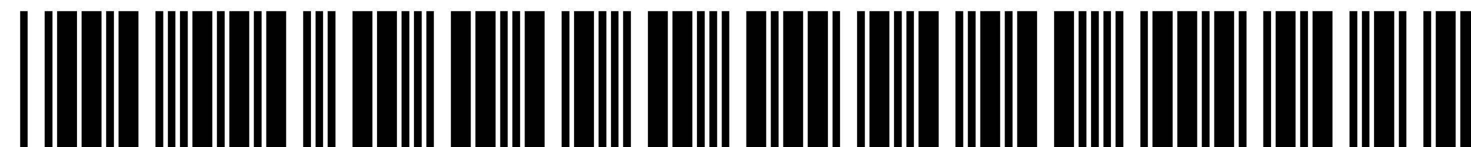

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Kondo et al.

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(45) **Date of Patent: Jun. 2, 2015**

(54) **SEMICONDUCTOR DEVICE**

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(21) Appl. No.: **14/145,141**

(22) Filed: **Dec. 31, 2013**

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H01L 29/78 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 29/66977*** (2013.01); ***H01L 29/7833*** (2013.01); ***H01L 29/66659*** (2013.01)

(58) **Field of Classification Search**
CPC ... H01L 29/78; H01L 29/0665; H01L 29/513; H01L 21/28273; H01L 21/28282; H01L 21/26586; H01L 27/1203; H01L 29/42312; H01L 29/78696; H01L 29/0843; H01L 29/66477; H01L 21/3083; H01L 27/092
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0228706	A1	9/2012	Sugizaki et al.	
2013/0075830	A1	3/2013	Miyano et al.	
2013/0134504	A1 *	5/2013	Kondo et al.	257/330
2014/0035040	A1 *	2/2014	Le Royer et al.	257/365

OTHER PUBLICATIONS

Jean-Pierre Colinge et al, "Nanowire Transistors without junctions", Nature Nanotechnology, vol. 5, Mar. 2010, pp. 225-229 (in English).
B. Ghosh et al., "Junctionless Tunnel Field Effect Transistor", IEEE Electron Device Letters, vol. 34, No. 5, May 2013, pp. 5874-586 (in English).
B. Ghosh et al., "Junctionless Tunnel Field Effect Transistor", IEEE Electron Device Letters, vol. 34, No. 5, May 2013, pp. 584-586 (in English).

* cited by examiner

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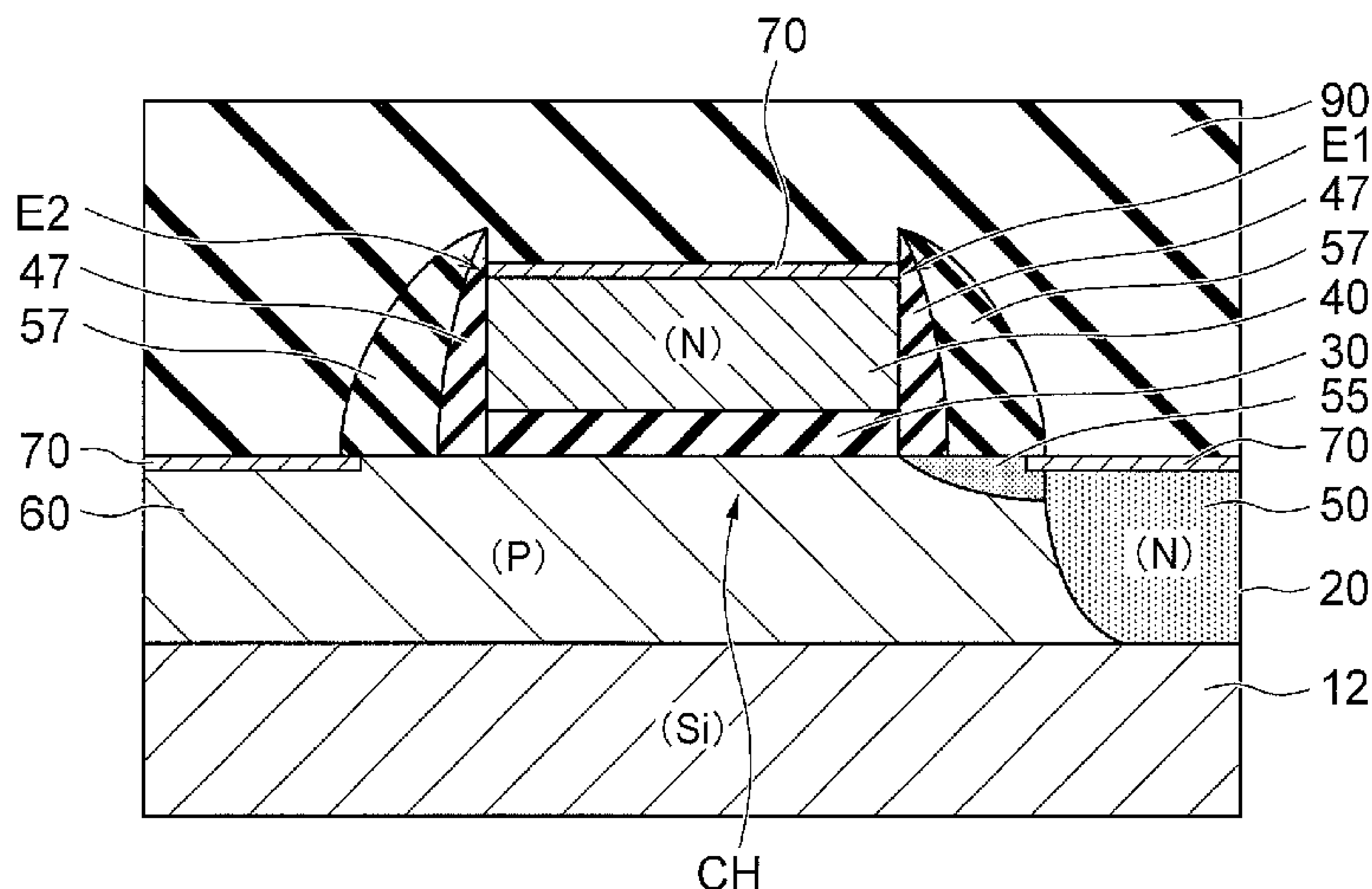
(57) **ABSTRACT**

A semiconductor device according to the present embodiment includes a semiconductor layer. A gate dielectric film is provided on a surface of the semiconductor layer. A gate electrode is provided on the semiconductor layer via the gate dielectric film. A drain layer of a first conductivity type is provided in a part of the semiconductor layer on a side of a first end of the gate electrode. A source layer of a second conductivity type is provided in a part of the semiconductor layer on a side of a second end of the gate electrode and below the gate electrode. The source layer has a substantially uniform impurity concentration at the part of the semiconductor layer below the gate electrode. Voltages of a same polarity are applied to the gate electrode and the drain layer.

20 Claims, 12 Drawing Sheets



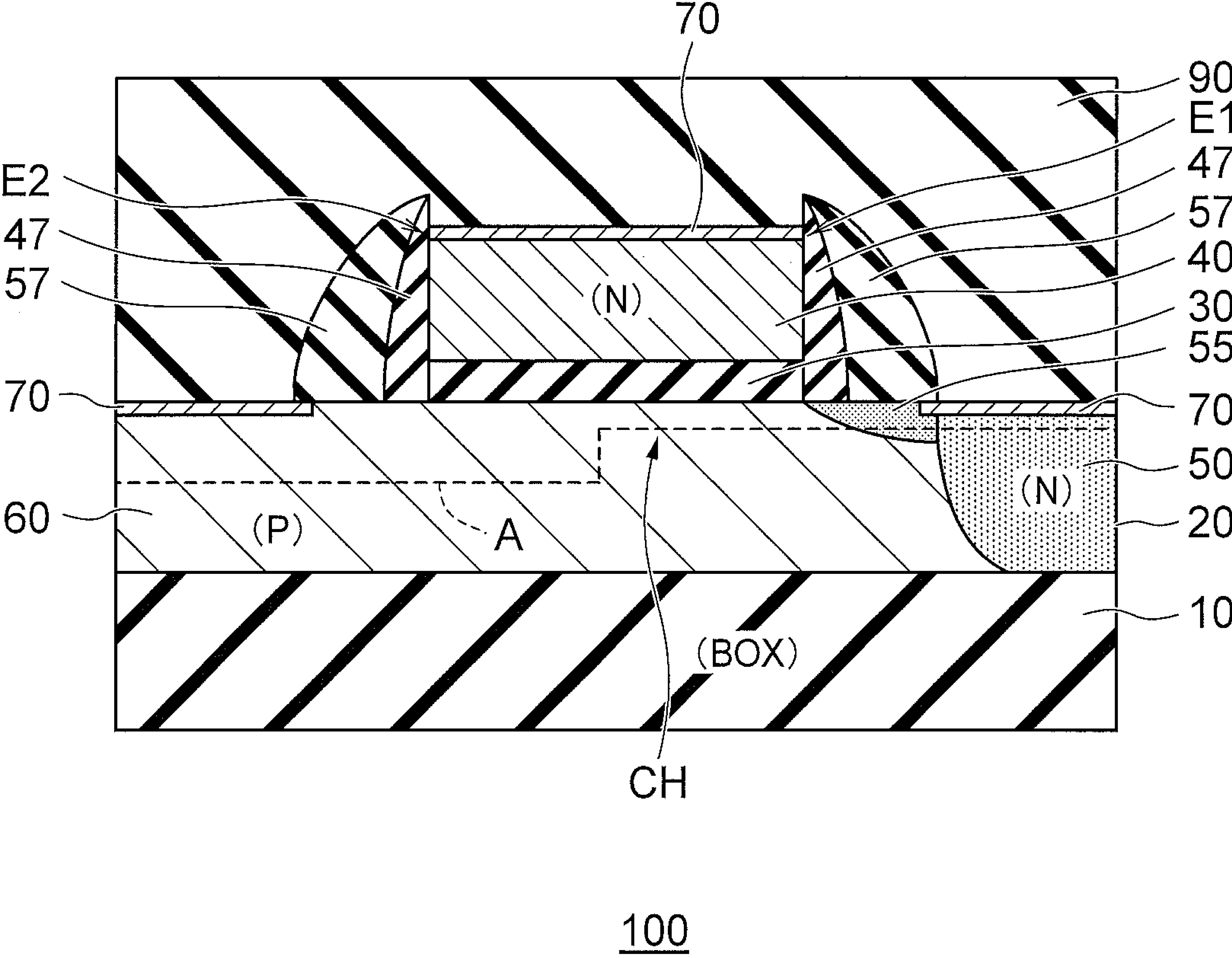


FIG.1

FIG.2A

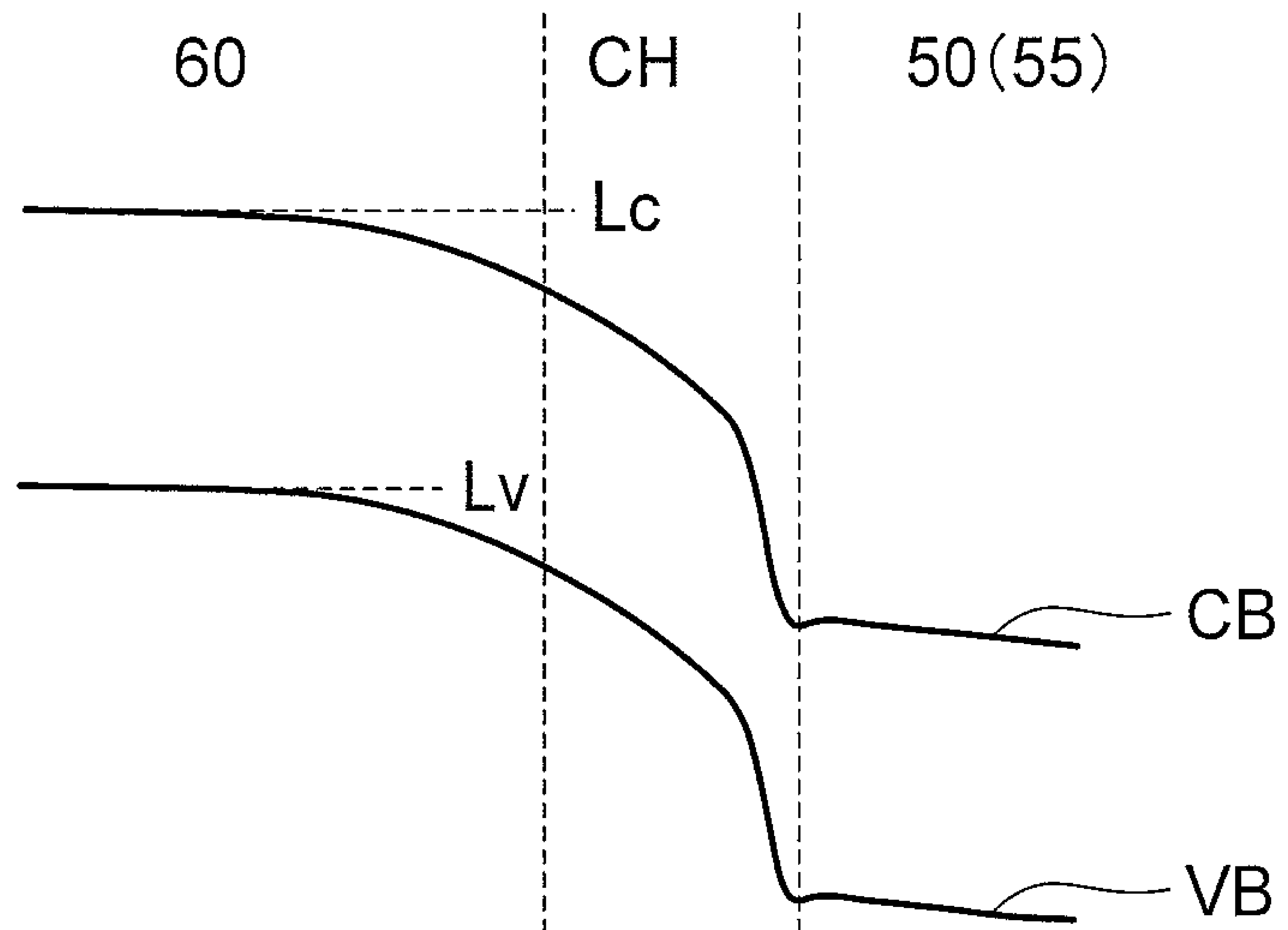
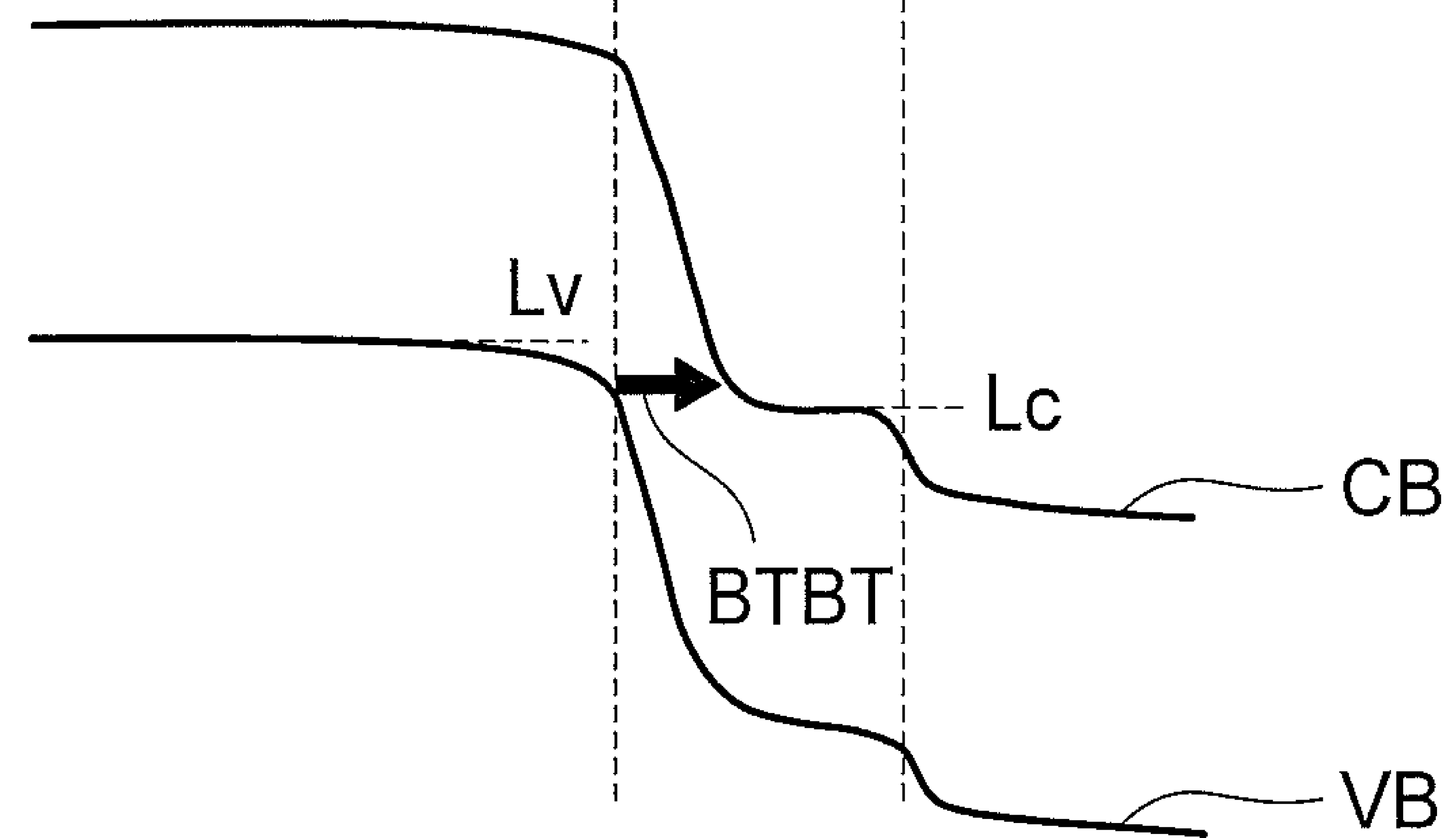


FIG.2B



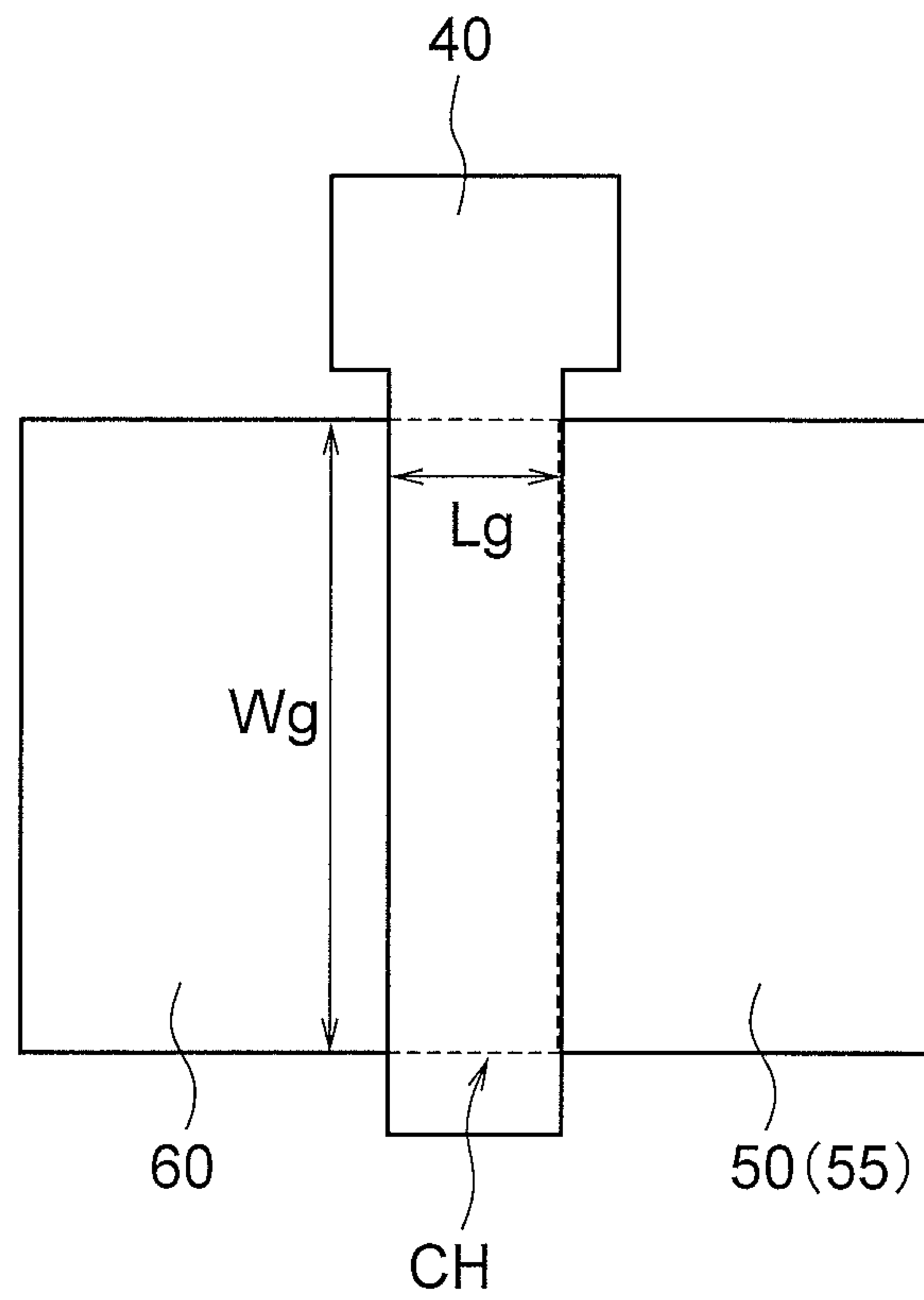


FIG.3

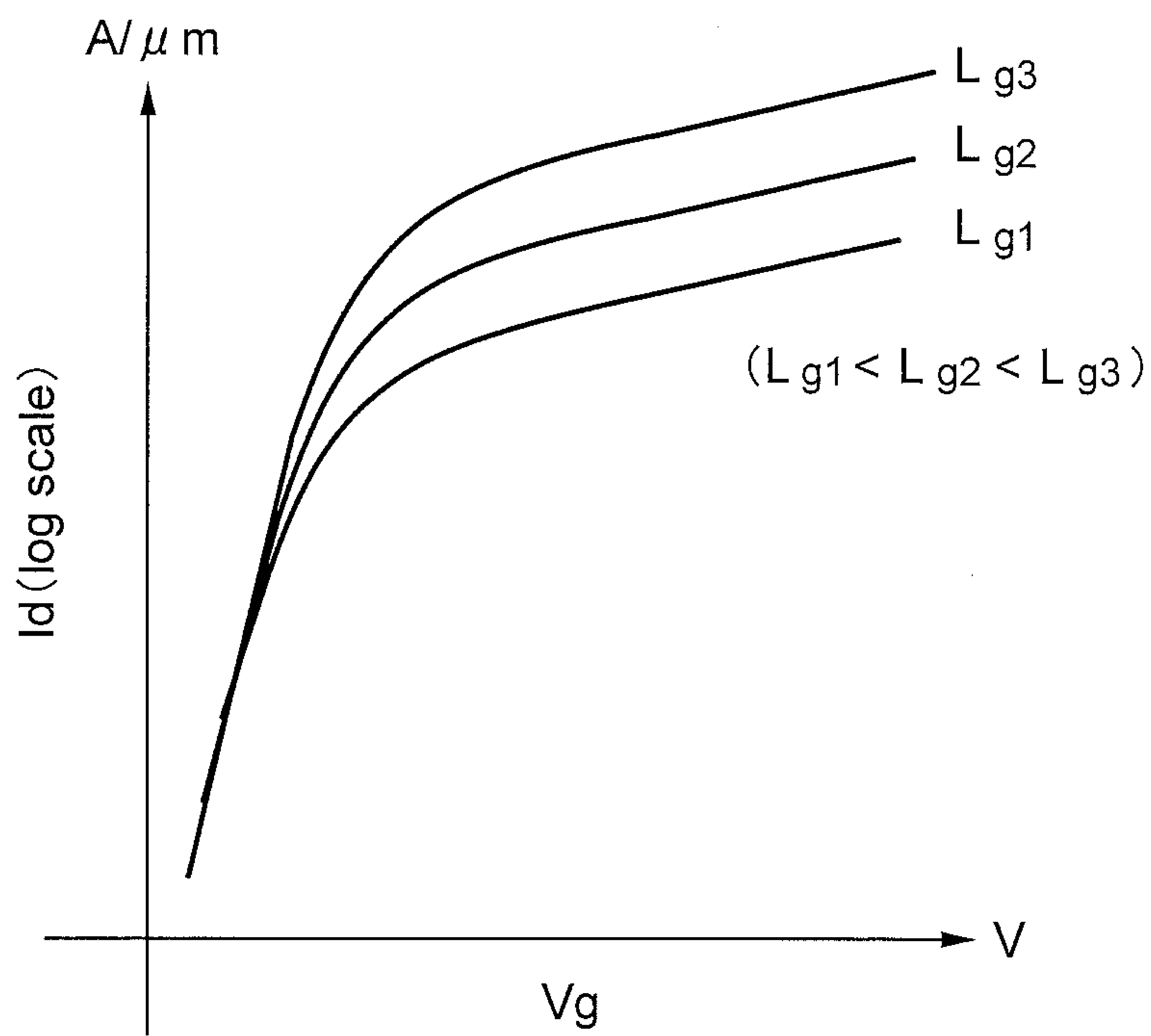


FIG.4

FIG.5A

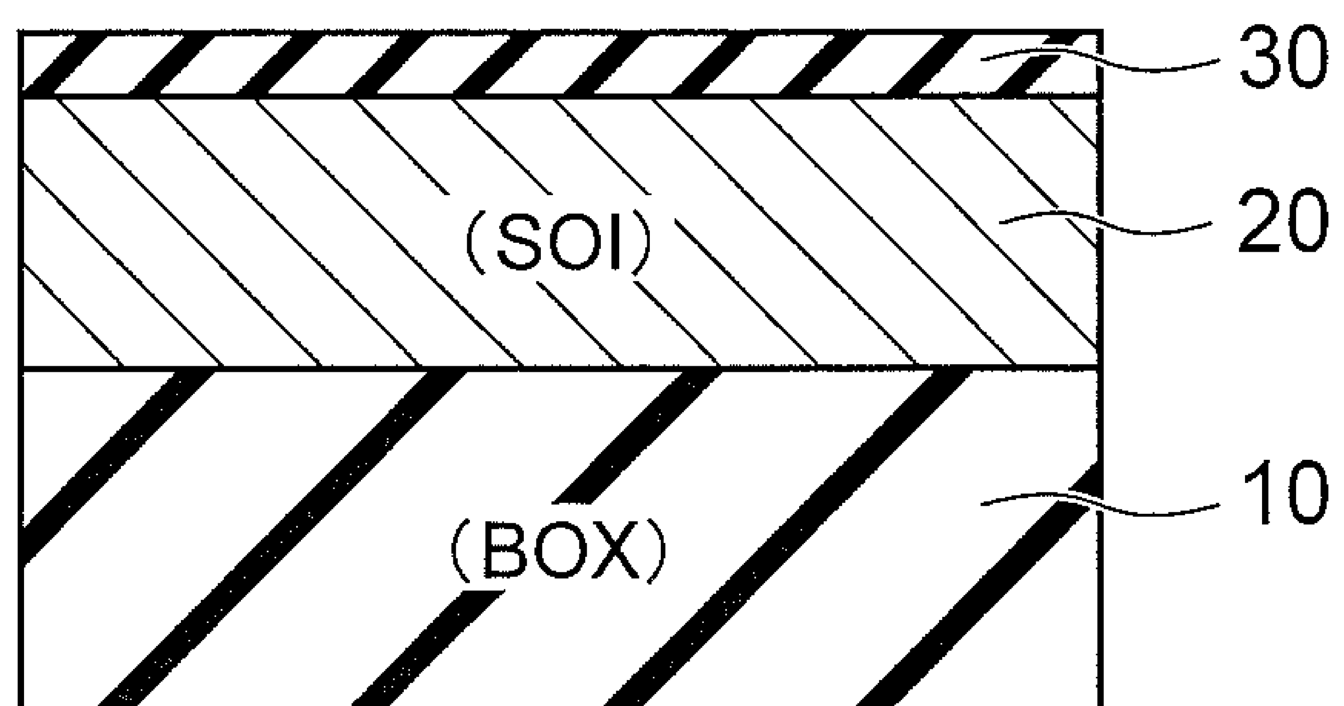
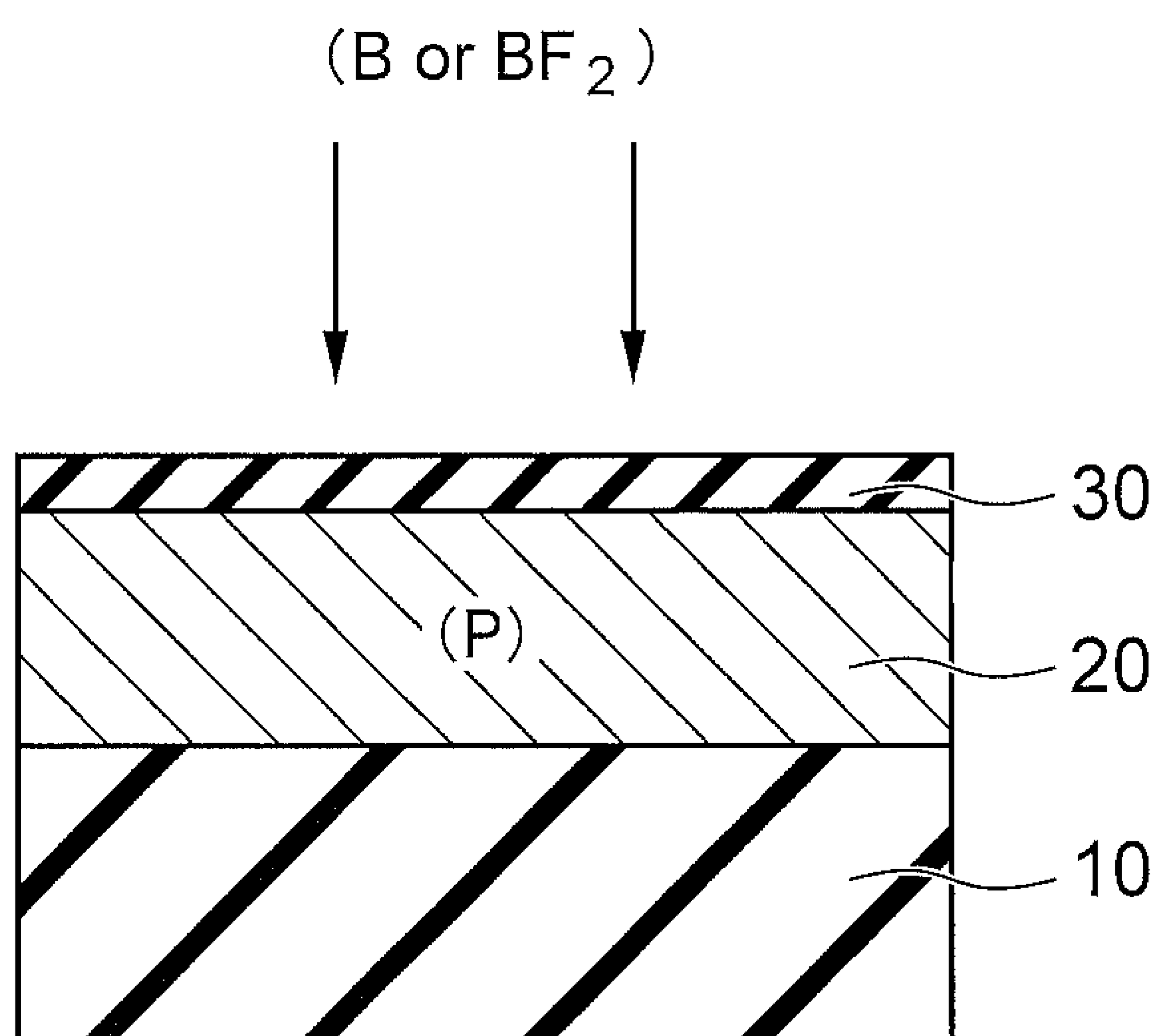


FIG.5B



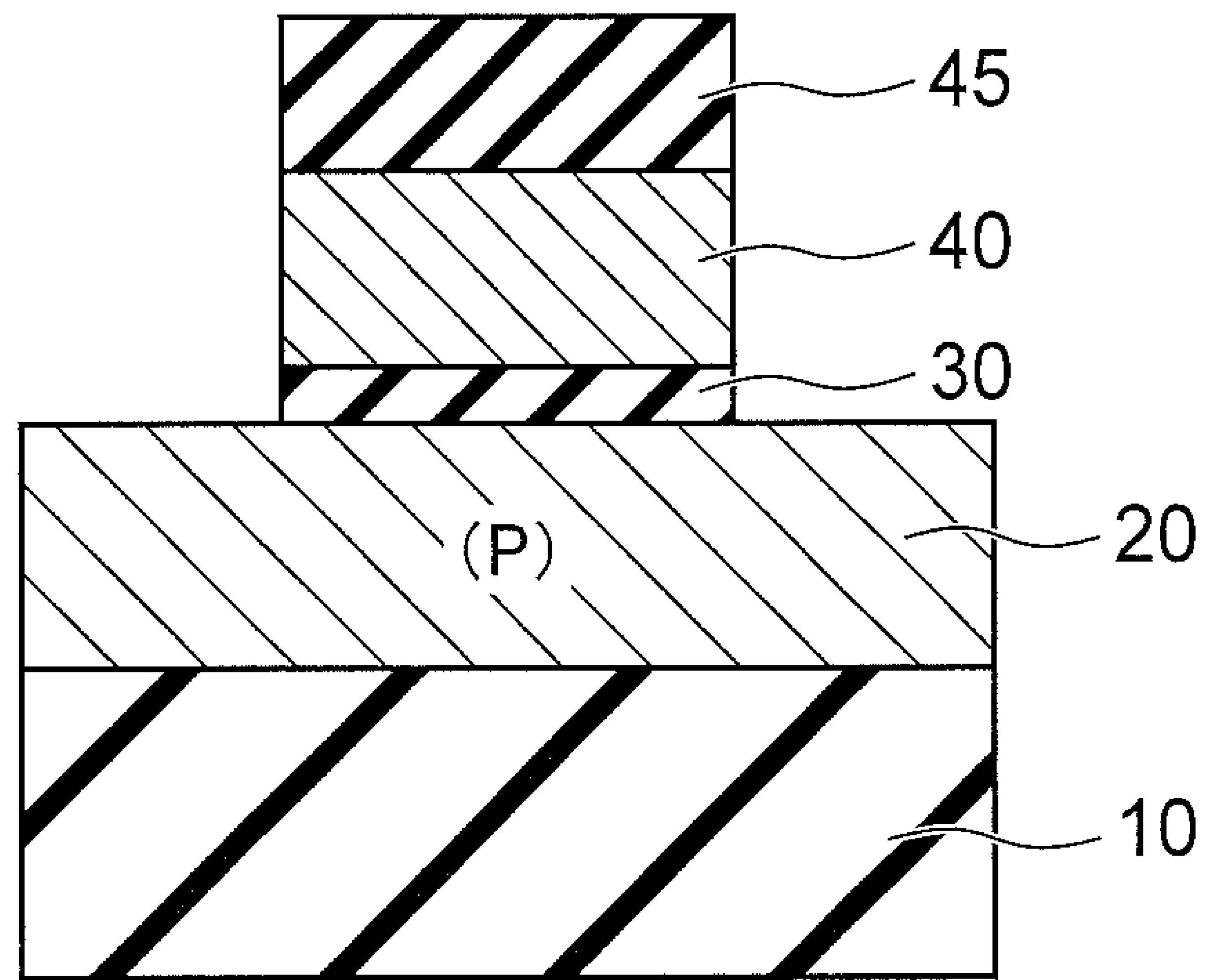


FIG.6A

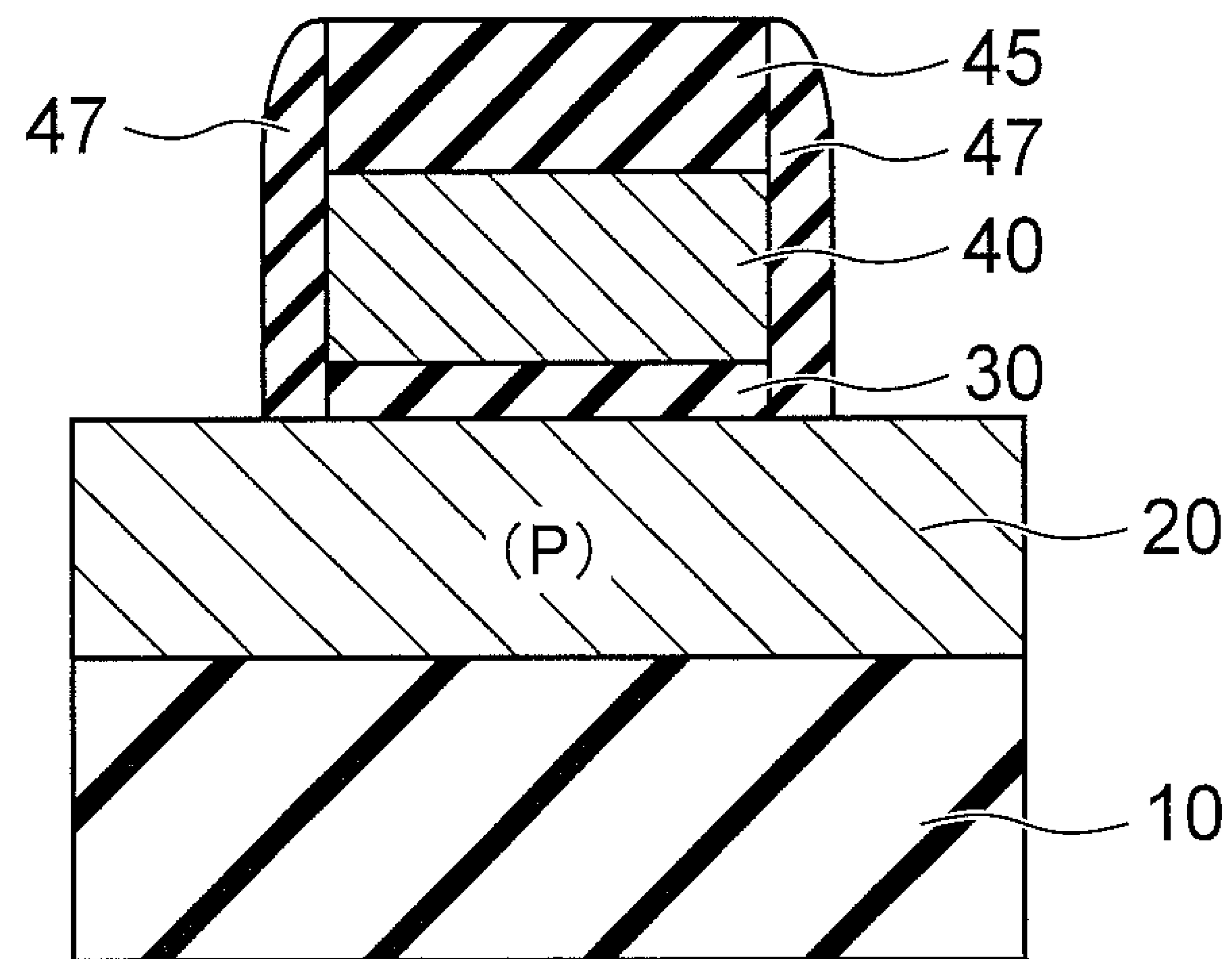


FIG.6B

FIG.7A

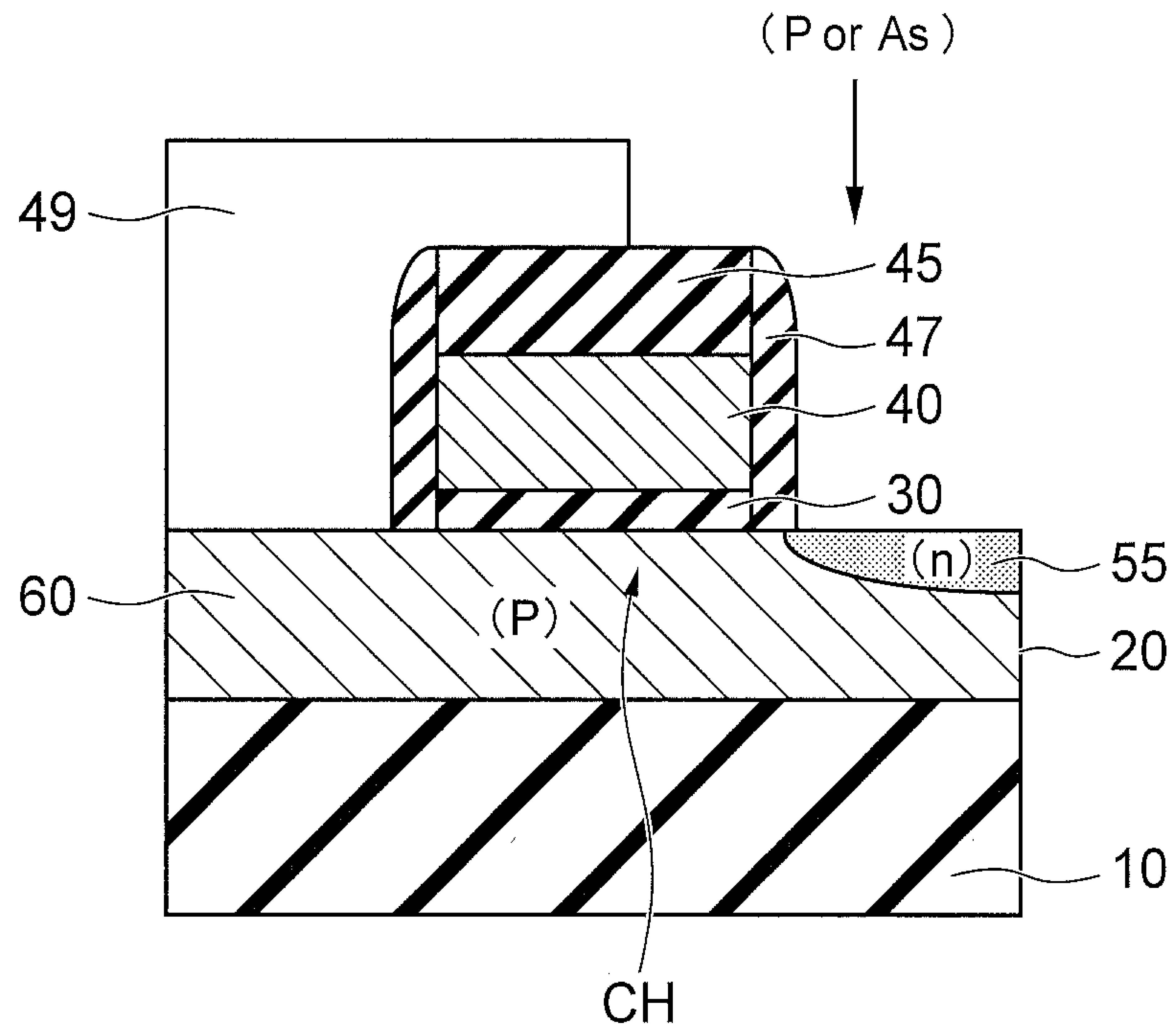
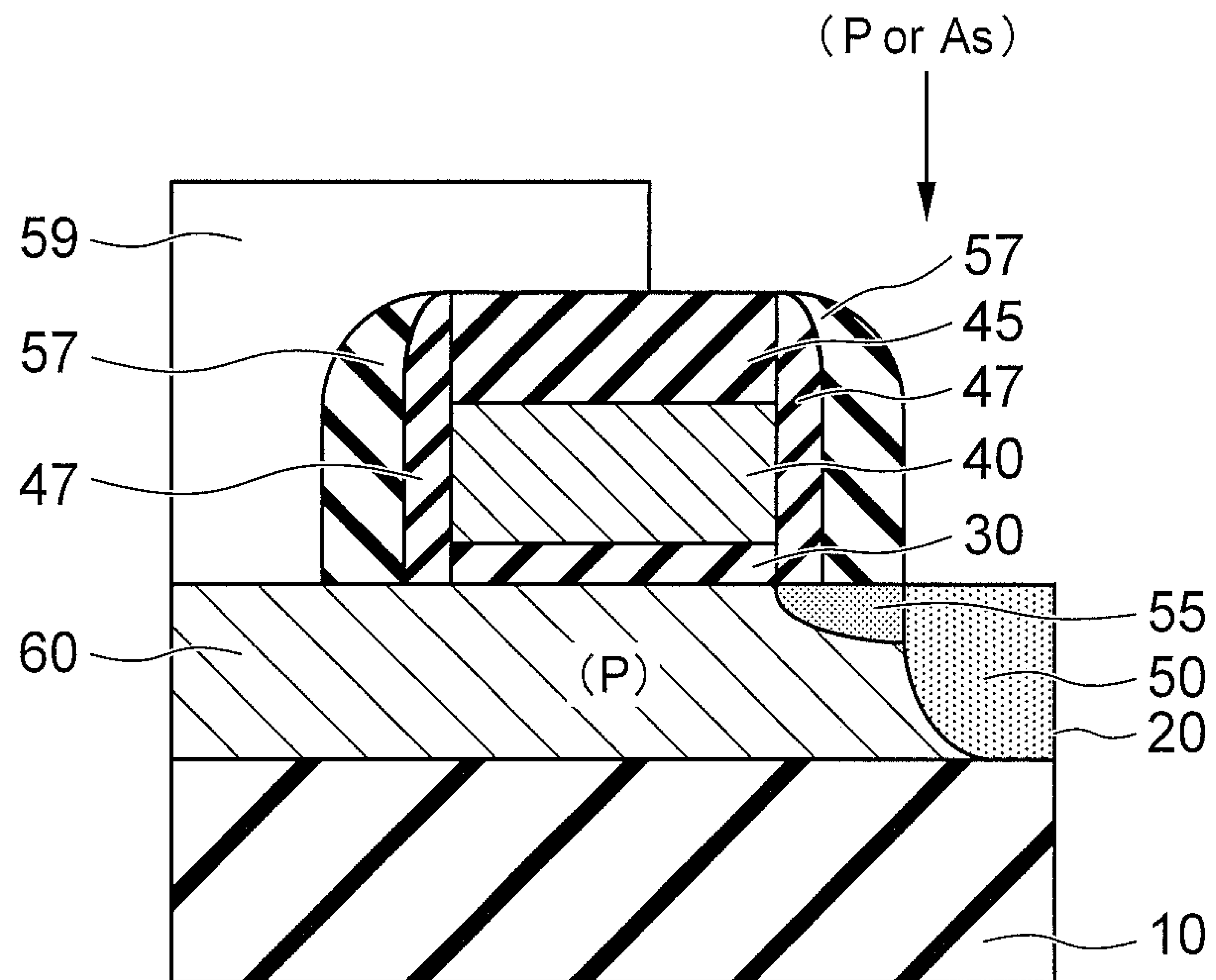


FIG.7B



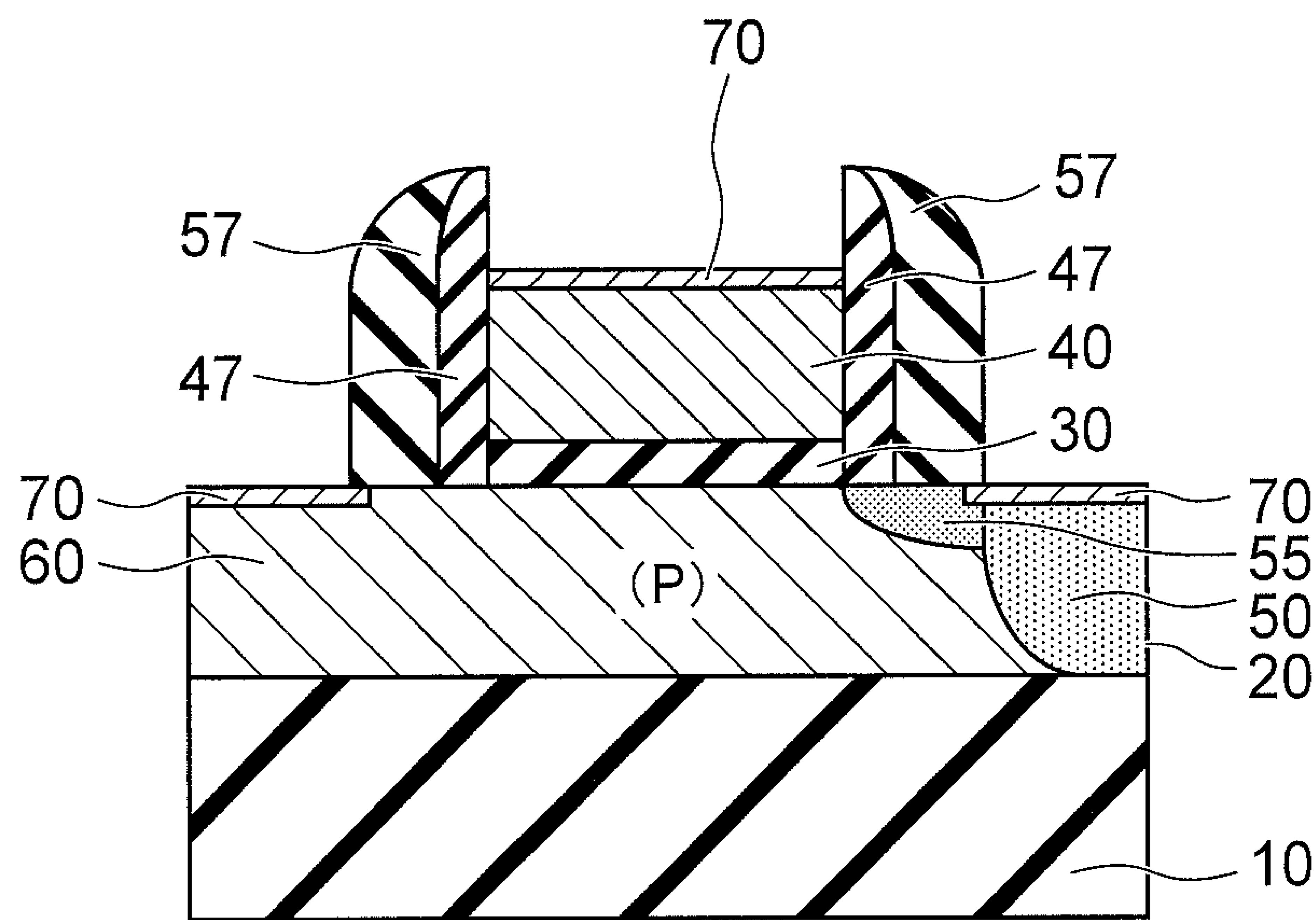
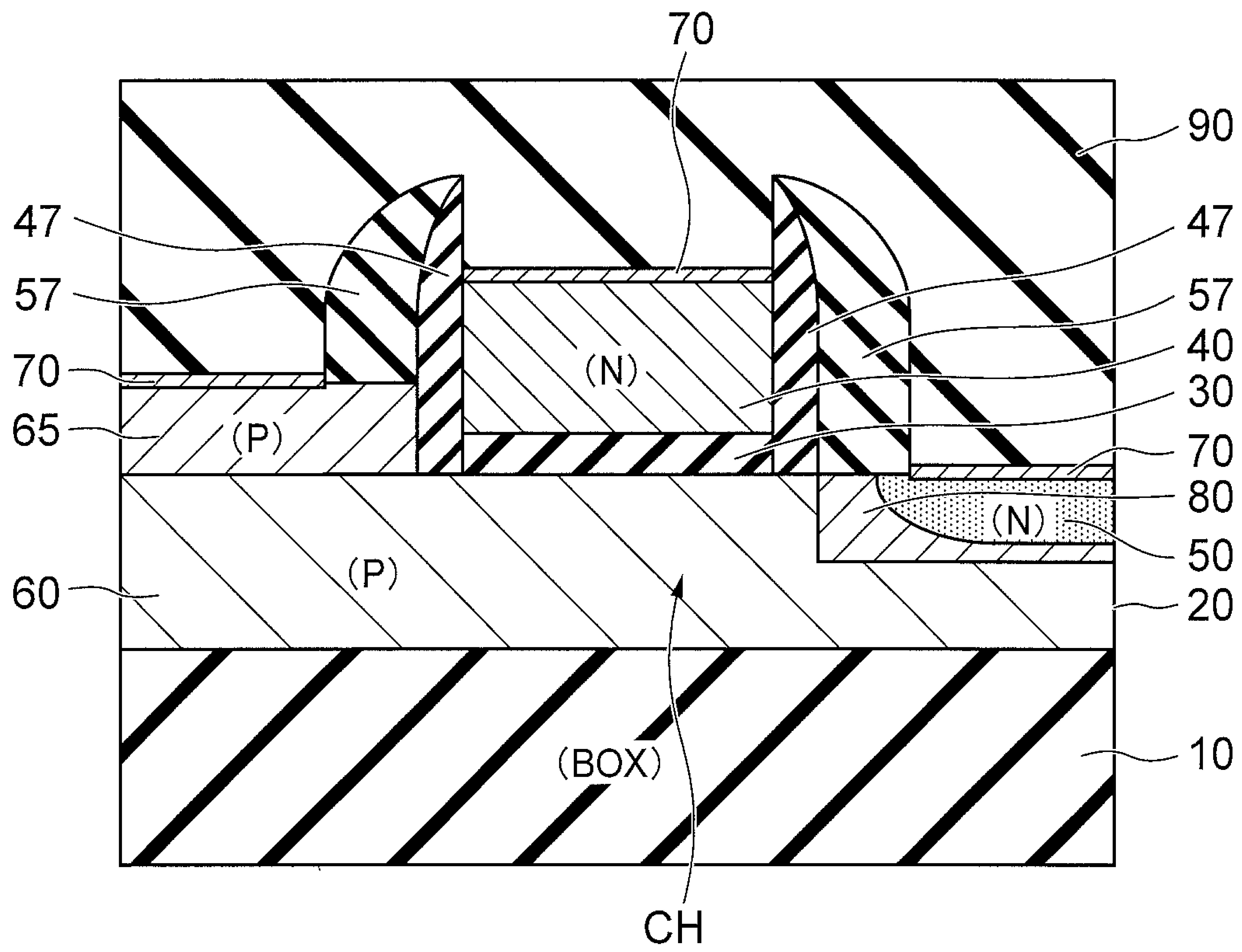


FIG.8



200

FIG.9

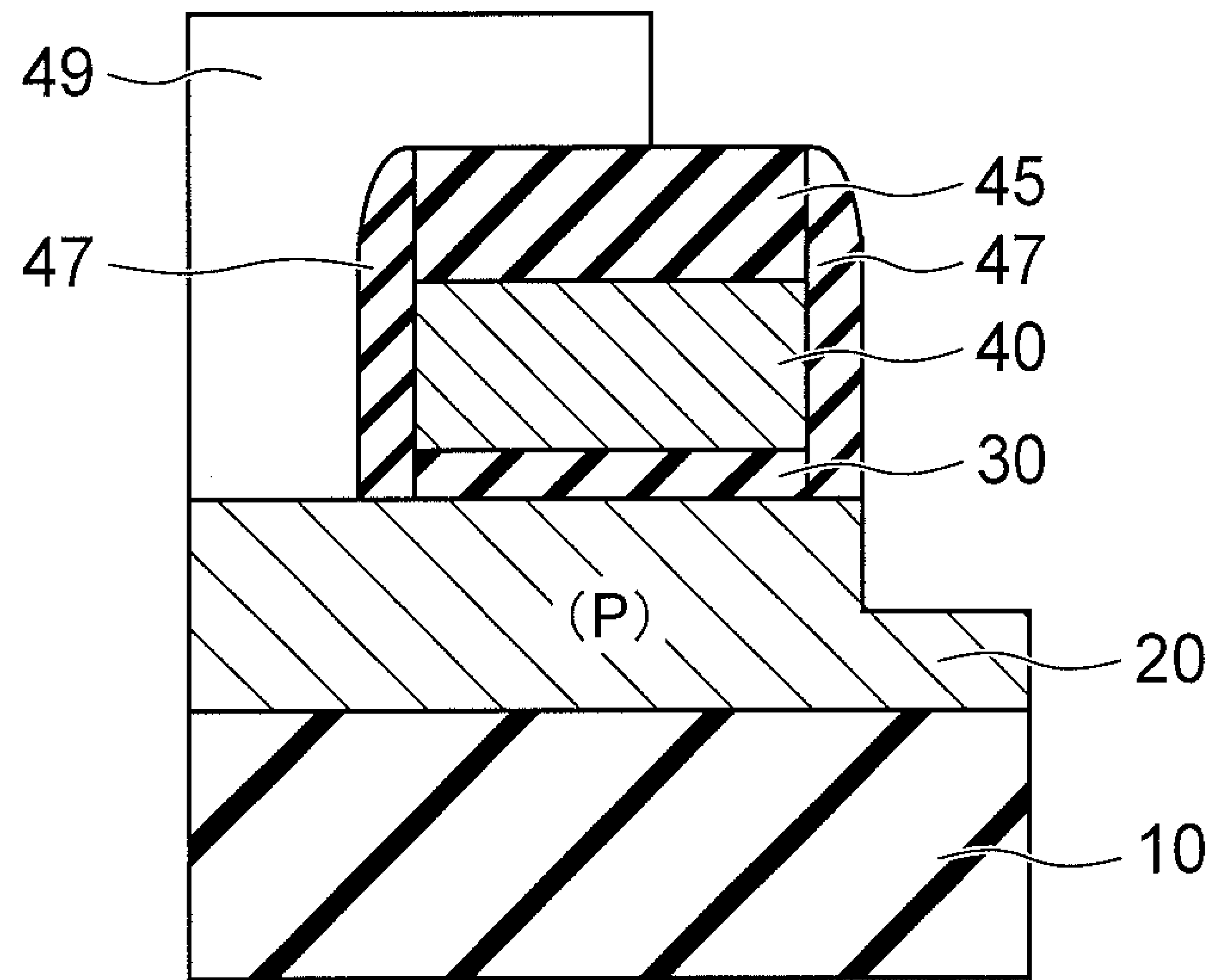


FIG.10A

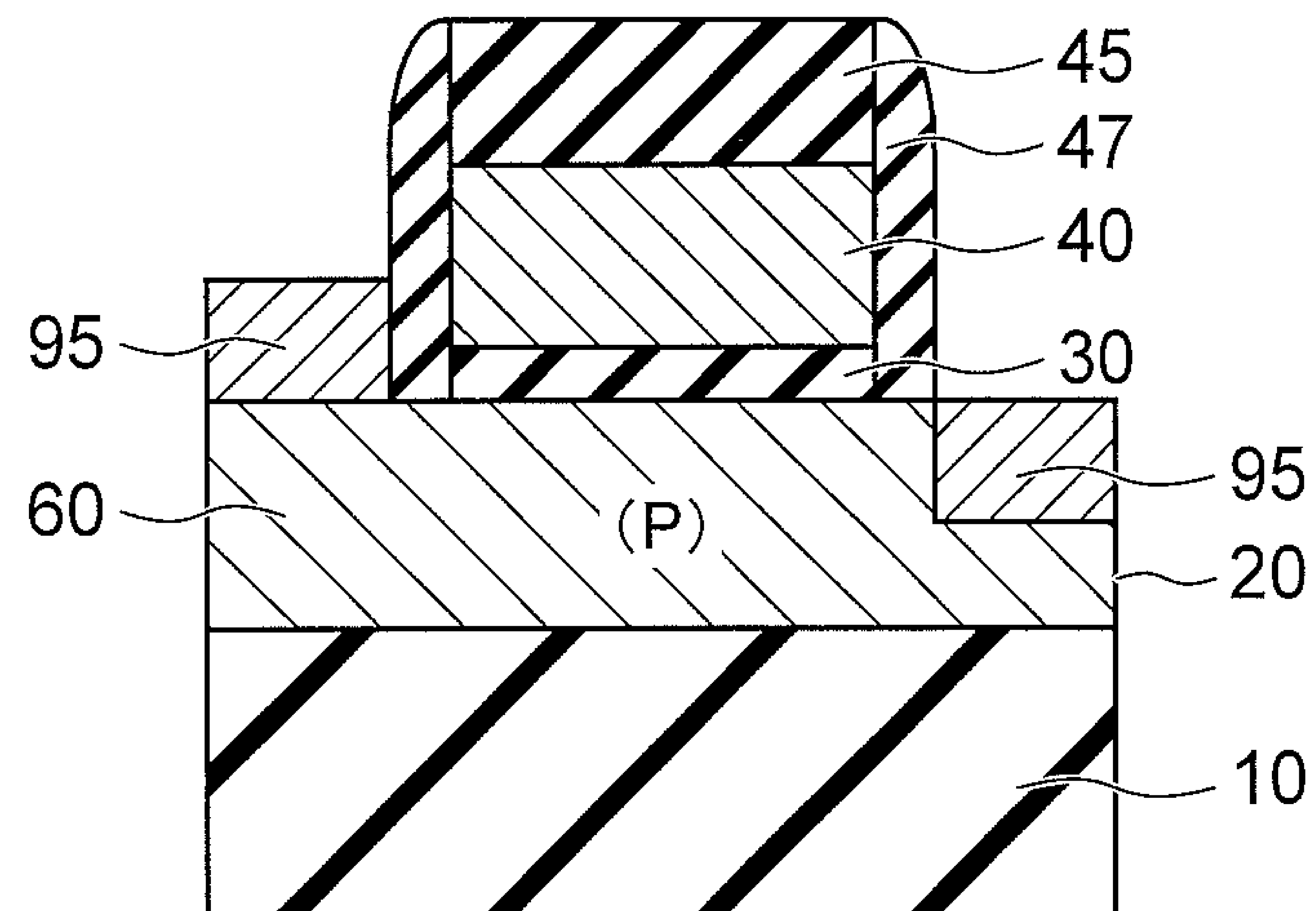


FIG.10B

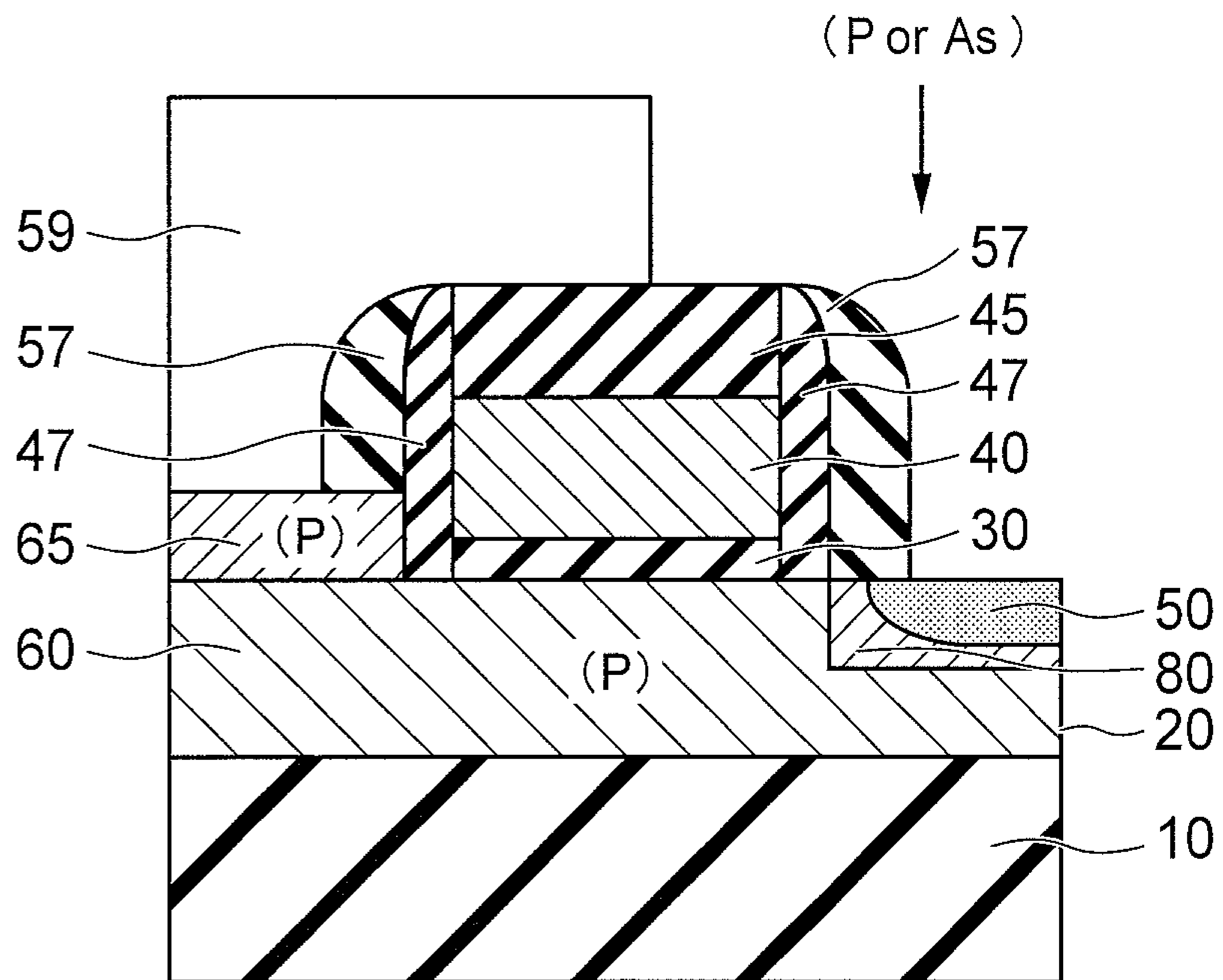


FIG.11A

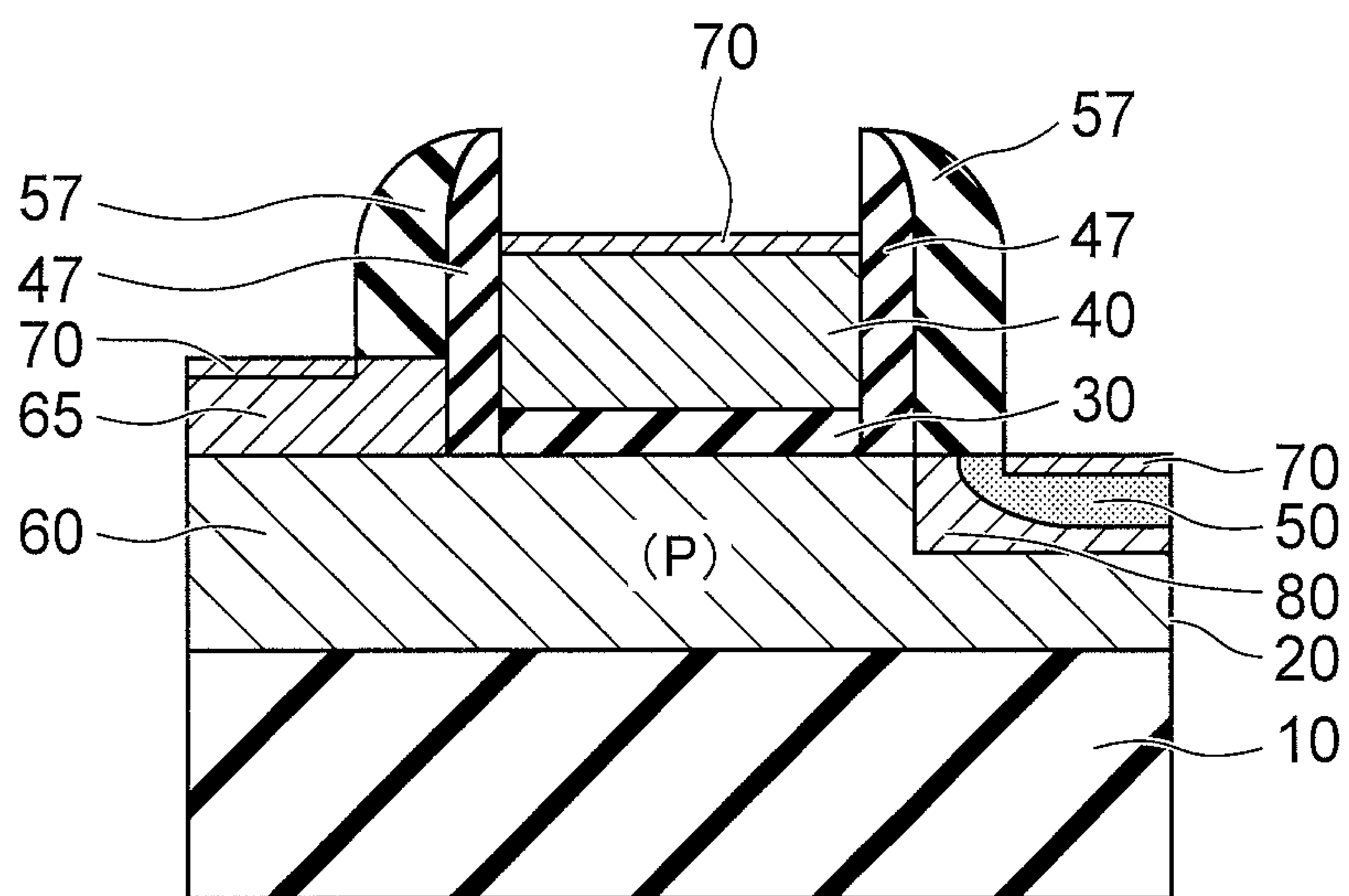


FIG.11B

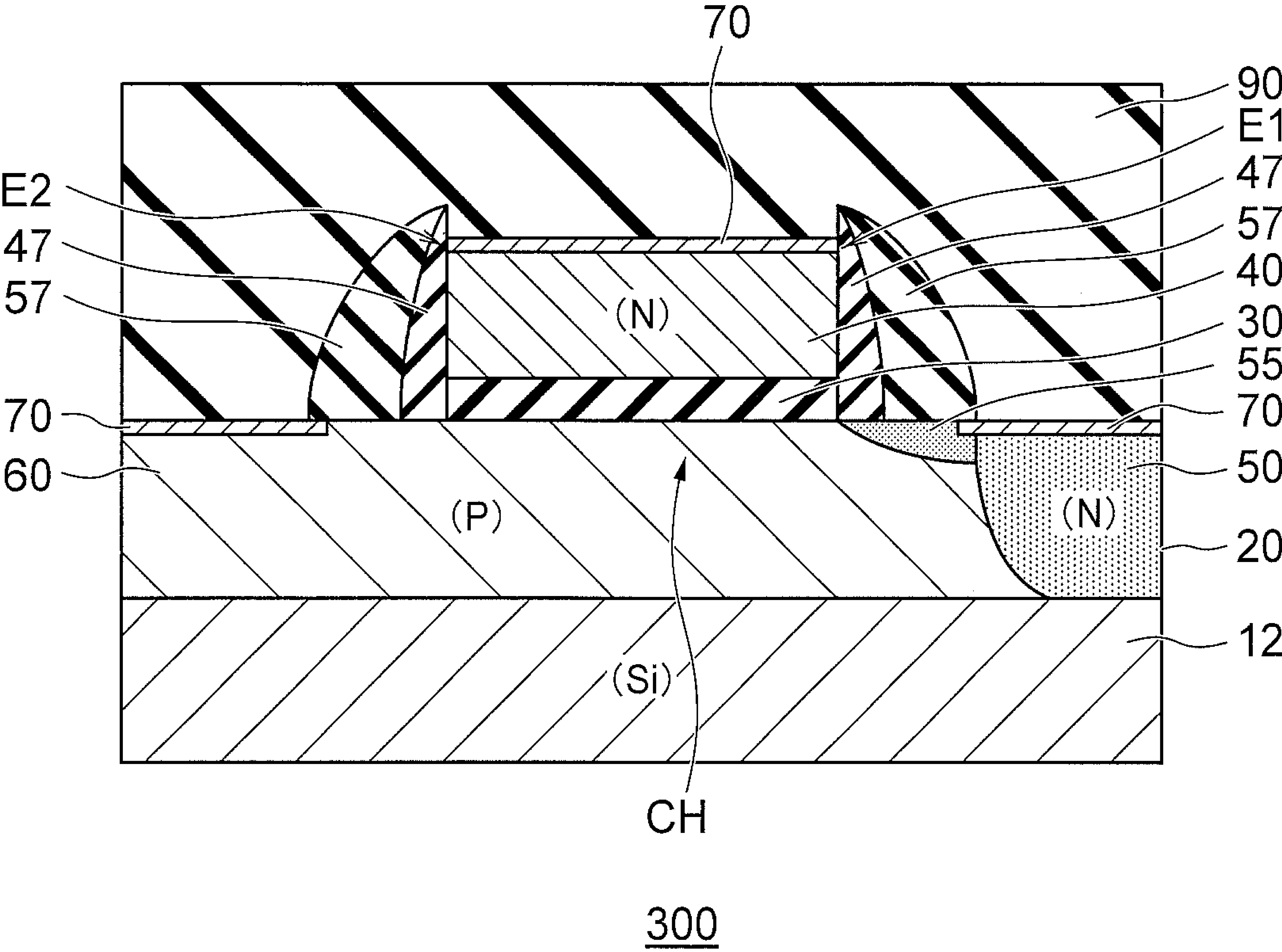


FIG.12

FIG.13A

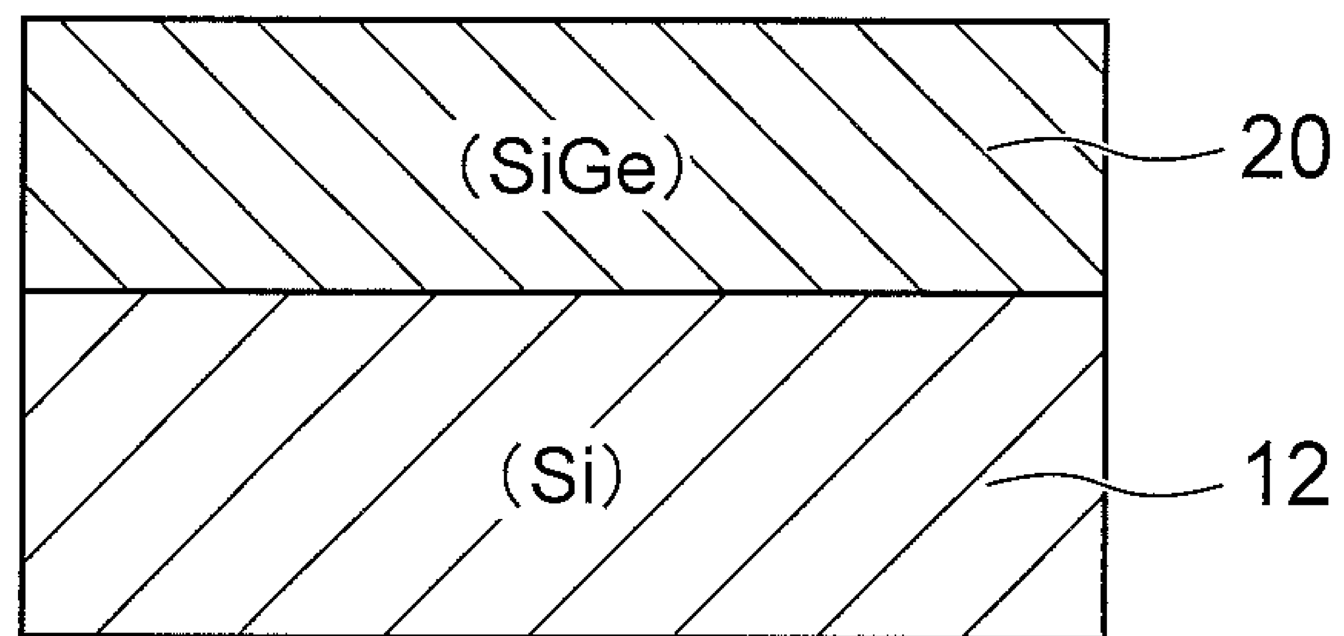
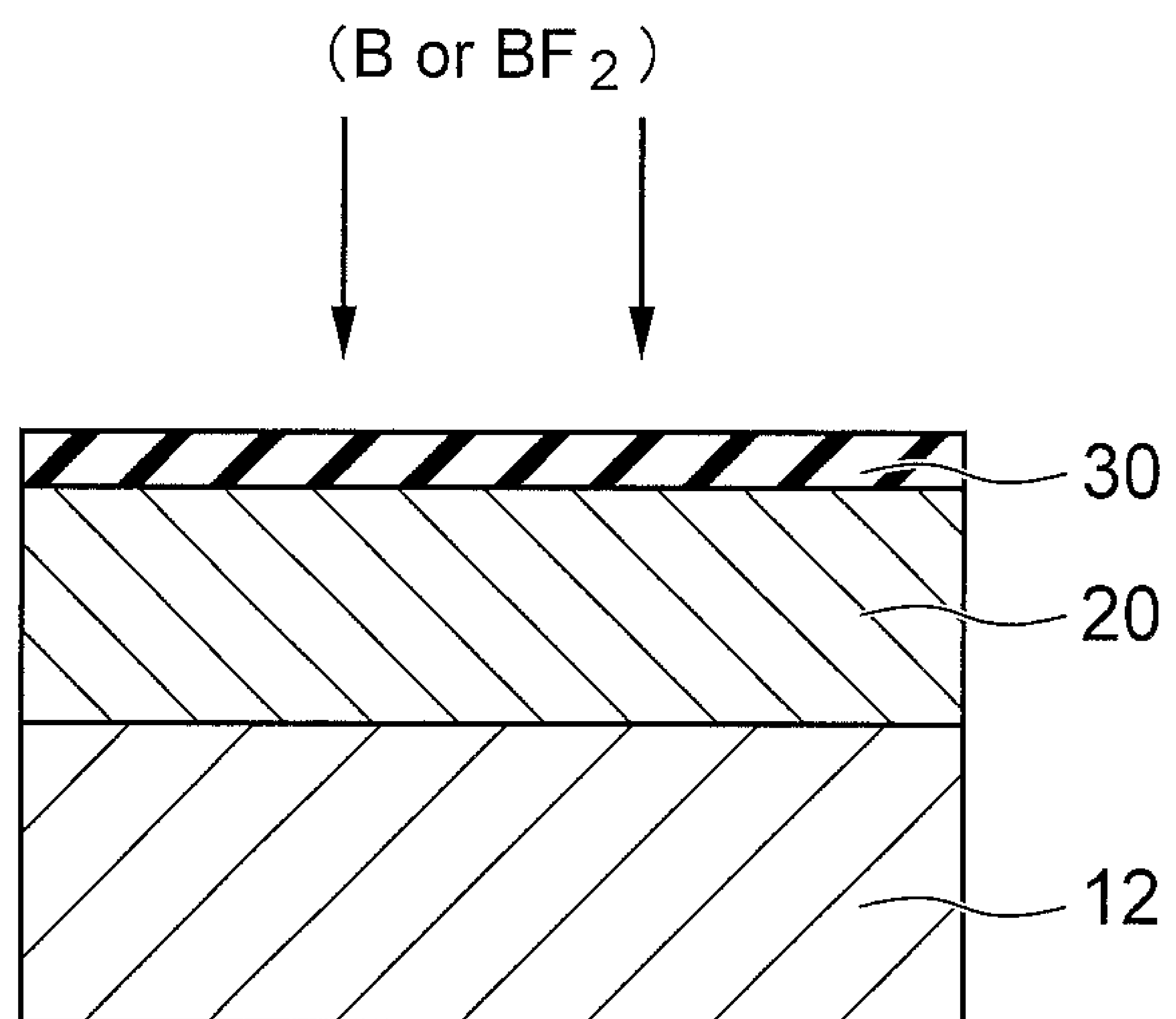


FIG.13B



SEMICONDUCTOR DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2013-190889, filed on Sep. 13, 2013, the entire contents of which are incorporated herein by reference.

FIELD

The embodiments of the present invention relate to a semiconductor device.

BACKGROUND

In recent years, a TFET (Tunnel Field-Effect Transistor) using a quantum mechanical effect of electrons has been developed. In the TFET, BTBT (Band To Band Tunneling) is caused between a source and a channel by applying a voltage to a gate electrode. This brings the TFET into an on-state.

In the TFET, it is considered to set the impurity concentration profile of a source layer to be abrupt in order to obtain steep sub-threshold characteristics. In order to set the impurity concentration profile to be abrupt, ion implantation for forming the source layer needs to be performed shallowly and in a high dose amount. It is known that the impurity concentration profile of a diffusion layer formed shallow and in a high concentration generally varies greatly in a wafer plane due to subsequent heat treatment or the like. Variations in the impurity concentration profile lead to variations in electrical characteristics (a threshold voltage, for example) of the TFET. For example, when variations in the threshold voltage are large, a power supply voltage for a circuit cannot be lowered in consideration of inclusion of a TFET with a high threshold voltage in the circuit. Therefore, a low-power circuit to which the power supply voltage is kept low is difficult to configure with the conventional TFETs.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view showing an example of a configuration of a TFET **100** according to a first embodiment;

FIGS. **2**A and **2**B are energy band diagrams showing an example of an operation of the TFET **100** according to the first embodiment;

FIG. **3** is a plan view showing the gate electrode **40**, the drain layer **50**, and the source layer **60** of the TFET **100**;

FIG. **4** is a graph showing relations between gate lengths Lg**1** to Lg**3** of the gate electrode **40** and the drain current Id (the on-state current);

FIGS. **5**A to **8** are cross-sectional views showing an example of a manufacturing method of the TFET **100** according to the first embodiment;

FIG. **9** is a cross-sectional view showing an example of a configuration of a TFET **200** according to a second embodiment;

FIGS. **10**A to **11**B are cross-sectional views showing an example of a manufacturing method of the TFET **200** according to the second embodiment;

FIG. **12** is a cross-sectional view showing an example of a configuration of a TFET **300** according to a third embodiment; and

FIGS. **13**A and **13**B are cross-sectional views showing an example of a manufacturing method of the TFET **300** according to the third embodiment.

DETAILED DESCRIPTION

Embodiments will now be explained with reference to the accompanying drawings. The present invention is not limited to the embodiments. In the embodiments, "an upper direction" or "a lower direction" refers to a relative direction when a direction of a surface of a semiconductor layer on which semiconductor elements are provided is assumed as "an upper direction". Therefore, the term "upper direction" or "lower direction" occasionally differs from an upper direction or a lower direction based on a gravitational acceleration direction.

A semiconductor device according to the present embodiment includes a semiconductor layer. A gate dielectric film is provided on a surface of the semiconductor layer. A gate electrode is provided on the semiconductor layer via the gate dielectric film. A drain layer of a first conductivity type is provided in a part of the semiconductor layer on a side of a first end of the gate electrode. A source layer of a second conductivity type is provided in a part of the semiconductor layer on a side of a second end of the gate electrode and below the gate electrode. The source layer has a substantially uniform impurity concentration at the part of the semiconductor layer below the gate electrode. Voltages of a same polarity are applied to the gate electrode and the drain layer.

First Embodiment

FIG. **1** is a cross-sectional view showing an example of a configuration of a TFET **100** according to a first embodiment. The TFET **100** can be used for a logic semiconductor integrated circuit such as a microprocessor or an ASIC (Application Specific Integrated Circuit).

The TFET **100** includes a BOX (Buried Oxide) layer **10**, a semiconductor layer **20**, a gate dielectric film **30**, a gate electrode **40**, an n-drain layer **50**, an n-extension layer **55**, a p-source layer **60**, a silicide layer **70**, a spacer **47**, a side wall film **57**, and an interlayer dielectric film **90**.

The semiconductor layer **20** is an SOI (Silicon On Insulator) layer provided on the BOX layer **10**. The gate dielectric film **30** is an insulating film provided on the surface of the semiconductor layer **20** and is formed using, for example, a silicon dioxide film or a dielectric material having a higher relative permittivity than that of the silicon dioxide film.

The gate electrode **40** is provided on the semiconductor layer **20** via the gate dielectric film **30** interposed therebetween. The gate electrode **40** is formed using, for example, a conductive material such as n-doped polysilicon.

The n-drain layer **50** is provided in a part of the semiconductor layer **20** located on the side of an end (a first end) E**1** of the gate electrode **40**. The n-extension layer **55** is provided to extend from the drain layer **50** to a part of the semiconductor layer **20** below the gate electrode **40**, on the surface-side of the semiconductor layer **20**. If the deep drain layer **50** extends to the end E**1** of the gate electrode **40** without the extension layer **55**, a GIDL (Gate Induced Drain Leakage) current may occur during standby (off-time) and sub-threshold swing characteristics (hereinafter, also "SS characteristics") may degrade. To suppress degradation in the SS characteristics, the extension layer **55** that is shallow and has a lower impurity concentration is formed.

The p-source layer **60** is provided in a part of the semiconductor layer **20** located on the side of the other end (a second end) E**2** of the gate electrode **40** and on a lower side of the gate electrode **40**. In the first embodiment, most parts of the bottom surface of the gate electrode **40** face the source layer **60**. That is, in the semiconductor layer **20**, the source layer **60** is

provided to extend from the other end E2 of the gate electrode **40** through under the bottom surface of the gate electrode **40** to near the end E1 of the gate electrode **40**. Therefore, a channel portion CH below the gate electrode **40** has the same conductive type as that of the source layer **60**. And, the channel portion CH has an impurity concentration substantially equal to that of the source layer **60**. That is, there is no pn-junction between the source layer **60** and the channel portion CH, and a concentration gradient therebetween is low. The source layer **60** and the channel portion CH extend at substantially uniform impurity concentrations. Accordingly, the channel portion CH is defined as a facing region to the bottom surface of the gate electrode **40** and to the source layer **60**.

The silicide layer **70** is provided on the gate electrode **40**, the drain layer **50**, and the source layer **60**. For example, the silicide layer **70** is a metal silicide obtained by reacting metal such as Ni, Co, or Ti with silicon.

The spacer **47** and the side wall film **57** are provided on side surfaces of the gate electrode **40**. The spacer **47** and the side wall film **57** are composed of, for example, an insulating film such as a TEOS (Tetraethyl orthosilicate) film or a silicon nitride film (Si_3N_4).

The interlayer dielectric film **90** covers the gate electrode **40**, the drain layer **50**, the source layer **60**, and the like. The interlayer dielectric film **90** is formed by, for example, an insulting film such as a TEOS film or a silicon dioxide film. Although not shown, an interconnection structure including contacts, metal interconnections, interlayer dielectric films, and the like is further provided in the interlayer dielectric film **90** or on the interlayer dielectric film **90**.

In the first embodiment, the source layer **60** is adjacent to the drain layer **50** (the extension layer **55**) in a region on the side of the end E1 of the gate electrode **40** (near the end E1). No intrinsic layer (hereinafter, also "i layer") is provided between the source layer **60** and the drain layer **50** (the extension layer **55**). In this case, the intrinsic layer is an intrinsic semiconductor layer not containing impurities (a semiconductor layer of an impurity concentration equal to or lower than $10^{16}/cm^3$).

A semiconductor integrated circuit using general MISFETs (Metal Insulator Semiconductor FETs) enables reduction in the power supply voltage by downscaling elements. In the general MISFET, however, the gate electrode is narrowed (short-channeled) due to the downscaling. Associated therewith, degradation in the SS characteristics and short-channel effects such as DIBL (Drain Induced Barrier Lowering) occur. Therefore, thinning of the gate dielectric film and increasing in the impurity concentration of the channel are required. In this case, however, increase in a gate leakage current or the GIDL current causes a problem. Therefore, it is difficult to further downscale the general MISFET.

On the other hand, the TFET **100** according to the first embodiment is controlled to be on/off using a tunneling effect of electrons, while voltages to be applied to the gate electrode **40**, the source layer **60**, and the drain layer **50** are almost equal to those in the MISFET. This can achieve steep SS characteristics. An operation of the TFET **100** according to the first embodiment is further explained below.

FIGS. **2**A and **2**B are energy band diagrams showing an example of an operation of the TFET **100** according to the first embodiment. FIG. **2**A is an energy band diagram of a case where the TFET **100** is in an off-state and FIG. **2**B is an energy band diagram of a case where the TFET **100** is in an on-state. FIGS. **2**A and **2**B are energy band diagrams at positions along

a broken line A in FIG. **1**. In this case, CB denotes the energy level of a conduction band and VB denotes the energy level of a valence band.

In the TFET **100** according to the first embodiment, voltages of the same polarity are applied to the gate electrode **40** and the drain layer **50** (the extension layer **55**). It is assumed, for example, that 0 volt is applied to the source layer **60** and that a positive voltage (1 volt, for example) is applied to the drain layer **50** (the extension layer **55**). That is, it is assumed that a reverse bias is applied to a junction between the source layer **60** and the drain layer **50** as shown in FIG. **2**A. When the TFET **100** is to be turned on, a positive voltage is applied to the gate electrode **40**.

When the gate electrode **40** is at a voltage lower than a threshold voltage, the TFET **100** is in an off-state. At that time, the energy level VB of the valence band of the source layer **60** and the energy level CB of the conduction band of the channel portion CH do not have substantially the same value and thus tunneling of electrons is forbidden. That is, while quite a small current (an off-leakage) due to the reverse bias flows at the junction between the source layer **60** and the drain layer **50**, the TFET **100** can be regarded as in an off-state.

When a positive voltage with respect to a source voltage is applied to the gate electrode **40**, the channel portion CH starts being depleted. At that time, the energy band of the channel portion CH is bent toward the valence band as shown in FIG. **2**B. When an energy level Lv of the balance band of the source layer **60** becomes equal to an energy level Lc of the conduction band of the surface of the channel portion CH, band to band tunneling (hereinafter, also "BTBT") of electrons occurs from the source layer **60** to the channel portion CH. A voltage of the gate electrode **40** at a time when the BTBT occurs is referred to as a threshold voltage. The threshold voltage is a gate voltage indicating the on-state of the TFET.

When a voltage higher than the threshold voltage is applied to the gate electrode **40**, a part of the channel portion CH in which the BTBT occurs extends from the side of the drain layer **50** to the side of the source layer **60**. That is, a region, where the energy level Lc of the conduction band on the surface of the channel portion CH is equal to or lower than the energy level Lv of the valence band of the source layer **60**, extends from the side of the drain layer **50** (the extension layer **55**) to the side of the source layer **60**.

Furthermore, when the voltage of the gate electrode **40** is further increased, the BTBT occurs in the whole of a region of the source layer **60** faced by the bottom surface of the gate electrode **40** (the whole channel portion CH). Accordingly, a current (Id) is increased by increasing the voltage of the gate electrode **40**. Because the BTBT occurs in the region of the source layer **60** faced by the bottom surface of the gate electrode **40** (the channel portion CH) in the on-state, the TFET **100** can obtain a current depending on the area of the channel portion CH (the channel length×the channel width).

A drain facing region, where the drain layer **50** or the extension layer **55** faces the bottom surface of the gate electrode **40**, is not included in the channel portion CH. However, when the drain facing region is fixed, the area of the channel portion CH can be adjusted by adjusting the area of the bottom surface of the gate electrode **40**. Therefore, it can be said that the current value in the on-state depends on the area of the bottom surface of the gate electrode **40**. When there is almost no drain facing region, the whole bottom surface of the gate electrode **40** faces the source layer **60**. In this case, the area of the bottom surface of the gate electrode **40** is almost equal to the area of the channel portion CH.

As described above, in the TFET **100** according to the first embodiment, the source layer **60** extends in the semiconduc-

tor layer **20** from the other end E**2** of the gate electrode **40** to near the end E**1** of the gate electrode **40**. Accordingly, most parts of the bottom surface of the gate electrode **40** face the source layer **60** and the source layer **60** is formed in the whole channel portion CH. That is, the channel portion CH is formed to have a substantially equal impurity concentration to that of the source layer **60**. Therefore, impurity concentration profiles of the source layer **60** and the channel portion CH are substantially even and smooth. By setting an impurity concentration profile from the source layer **60** to the channel portion CH to be substantially even in this way, variations of the impurity concentration profile in the wafer plane can be also suppressed. Thus, variations in the electrical characteristics (the threshold voltage, for example) of the TFET **100** in the wafer plane are suppressed. And, threshold voltages of a plurality of the TFETs **100** included in a semiconductor integrated circuit can be formed in nearly designed values. As a result, the power supply voltage of the semiconductor integrated circuit can be lowered, therefore, the power consumption can be suppressed.

In the TFET **100** according to the first embodiment, the area of the channel portion CH (the channel length×the channel width) can be adjusted by adjusting the area of the gate electrode **40** (the gate length×the gate width). For example, FIG. **3** is a plan view showing the gate electrode **40**, the drain layer **50**, and the source layer **60** of the TFET **100**. As shown in FIG. **3**, the area of the channel portion CH (an area where the gate electrode **40** and the source layer **60** face each other) can be adjusted by a gate length Lg and a gate width Wg of the gate electrode **40**. Therefore, an on-state current can be controlled by adjusting a size (the gate length and/or the gate width) of the gate electrode **40**. For example, FIG. **4** is a graph showing relations between gate lengths Lg**1** to Lg**3** of the gate electrode **40** and the drain current Id (the on-state current). In this case, Lg**1**<Lg**2**<Lg**3**. As shown in FIG. **4**, when the gate length is increased from Lg**1** to Lg**3**, the drain current Id in the on-state increases. When the drain current Id in the on-state changes, the SS characteristics also change. Therefore, according to the first embodiment, not only steep SS characteristics can be obtained, but also the TFET **100** having threshold voltages corresponding to various use applications can be formed by adjusting the size of the gate electrode **40**.

FIGS. **5**A to **8** are cross-sectional views showing an example of a manufacturing method of the TFET **100** according to the first embodiment.

The gate dielectric film **30** is first formed on the semiconductor layer **20** as shown in FIG. **5**A. The semiconductor layer **20** can be an SOI layer of an SOI substrate, a silicon layer formed using a silicon substrate, or a semiconductor layer using a group III-V compound semiconductor substrate. The semiconductor layer **20** can be a semiconductor layer epitaxially grown on an arbitrary substrate. For example, the semiconductor layer **20** can be a SiGe layer epitaxially grown on an SOI substrate or a bulk substrate.

The gate dielectric film **30** can be a thermally-oxidized film obtained by thermally oxidizing the semiconductor layer **20**. Alternatively, the gate dielectric film **30** can be a TEOS film, a silicon nitride film (such as Si_3N_4), SiON, or a high dielectric film formed by a CVD (Chemical Vapor Deposition) method.

The source layer **60** and the channel portion CH are then formed by ion implantation as shown in FIG. **5**B. Ions to be implanted are, for example, p-type impurities such as B or BF_2. Activation annealing such as RTA (Rapid Thermal Annealing) is then performed. This forms the source layer **60** and the channel portion CH in substantially uniform impurity concentrations.

The material of the gate electrode **40** is then deposited on the gate dielectric film **30**, and the material of a hard mask **45** is deposited on the material of the gate electrode **40**. The material of the gate electrode **40** is formed using, for example, polycrystalline silicon doped with n-type impurities such as phosphorus or arsenic. The material of the hard mask **45** is formed using, for example, an insulating film such as a silicon nitride film. The material of the hard mask **45** is then processed into a layout pattern of the gate electrode **40** using a lithographic technique and an RIE (Reactive Ion Etching) method. The gate electrode **40** and the gate dielectric film **30** are processed by the RIE method using the hard mask **45** as a mask. In this way, a structure shown in FIG. **6**A is obtained. A combination of the gate electrode **40** and the gate dielectric film **30** may be a combination of polysilicon and SiON or a combination of a metal gate and a high dielectric film. When the combination of the gate electrode **40** and the gate dielectric film **30** is a combination of a metal gate and a high dielectric film, the material of the metal gate may be TiN, TaOx, or the like and the material of the high dielectric film may be HfOx, HfON, HfSiON, Al_2O_3, or the like. In this case, x is a positive number. The shape of the gate electrode **40** may have a Fin-gate or multilayered-gate structure.

An insulating film such as TEOS is then deposited on side surfaces of the gate electrode **40** and an upper surface of the hard mask **45** using the CVD method. The insulating film is then anisotropically etched using the RIE method to leave the spacer **47** on the side surfaces of the gate electrode **40** as shown in FIG. **6**B.

The source layer **60** is then covered with a photoresist **49** using the lithographic technique as shown in FIG. **7**A. Ions of n-type impurities (phosphorus or arsenic, for example) are implanted in a part of the semiconductor layer **20** on the drain side using the photoresist **49** as a mask. At that time, implantation of the n-type impurities changes the part of the semiconductor layer **20** on the drain side from the p type to the n type. The n-type impurities are controlled to be locally implanted to shallow positions in the semiconductor layer **20**. The extension layer **55** is formed in this way.

After the photoresist **49** is removed, an insulating film such as TEOS is further deposited on the spacer **47** and the hard mask **45** using the CVD method. The insulating film is then anisotropically etched using the RIE method to cause the side wall film **57** to further remain on side surfaces of the spacer **47** as shown in FIG. **7**B. In this way, the spacer **47** and the side wall film **57** are formed on the side surfaces of the gate electrode **40**.

The source layer **60** is then covered with a photoresist **59** using the lithographic technique. Ions of n-type impurities (phosphorus or arsenic, for example) are implanted in a part of the semiconductor layer **20** on the drain side using the photoresist **59** as a mask. In the embodiment, the n-type impurities are controlled to be implanted to deeper positions than at the time of formation of the extension layer **55**. Activation annealing is then performed using the RTA method or the like. In this way, the drain layer **50** and the extension layer **55** are formed.

After the photoresist **59** is removed, the hard mask **45** is removed using wet etching. Metal such as Ni, Co, or Ti is then deposited on the gate electrode **40**, the source layer **60**, and the drain layer **50** (or the extension layer **55**) using a PVD (Physical Vapor Deposition) method. By reacting the metal layer with silicon, the silicide layer **70** is formed on the gate electrode **40**, the source layer **60**, and the drain layer **50** (or the extension layer **55**).

The interlayer dielectric film **90**, contacts (not shown), metal interconnections (not shown), and the like are then

formed to complete the TFET **100** shown in FIG. **1**. While the n-TFET is explained in the first embodiment, a p-TFET can be easily formed by changing the conductivity type of the impurities. The p-TFET is in an on-state when a gate voltage with reference to a source voltage is lower than a threshold voltage and is in an off-state when the gate voltage is higher than the threshold voltage. For example, in the case of a p-TFET in a CMOS inverter, a positive voltage is applied to a source. Therefore, the p-TFET is turned on by setting a gate voltage at 0 volt, while the p-TFET is turned off by setting the gate voltage at a power supply voltage (1 volt, for example). The effect of the first embodiment is not lost also in the p-TFET.

In the first embodiment, the source layer **60** and a diffusion layer of the channel portion CH are simultaneously formed and have substantially uniform impurity concentrations as shown in FIG. **5**B. Therefore, according to the first embodiment, the impurity concentration profile from the source layer **60** to the channel portion CH can be set substantially even, which prevents formation of a junction between the source layer **60** and the channel portion CH. Accordingly, as described above, variations in the electrical characteristics of the TFET **100** in the wafer plane are suppressed. Therefore, the threshold voltages of the TFETs **100** included in a semiconductor integrated circuit can be formed in nearly designed values. This enables to reduce the power supply voltage, resulting in reduction of the power consumption.

Second Embodiment

FIG. **9** is a cross-sectional view showing an example of a configuration of a TFET **200** according to a second embodiment. In the TFET **200** according to the second embodiment, a low concentration layer **80** is provided between the drain layer **50** and the source layer **60**. The low concentration layer **80** is formed using, for example, a silicon crystal layer epitaxially grown. The low concentration layer **80** is a semiconductor layer of an impurity concentration lower than those of the source layer **60**, the drain layer **50**, and the channel portion CH. The low concentration layer **80** is formed, for example, by forming a silicon layer not doped with impurities. Furthermore, the TFET **200** does not have the extension layer **55**. Therefore, the drain layer **50** is distanced from just underneath of the gate electrode **40**, and the source layer **60** is adjacent to the low concentration layer **80** in a region of the semiconductor layer **20** on the side of one end of the gate electrode **40**. That is, the drain layer **50** is offset from the channel portion CH.

The TFET **200** has a p-diffusion layer **65** on the source layer **60**. The diffusion layer **65** is a silicon crystal layer epitaxially grown at the same time as the low concentration layer **80**. The diffusion layer **65** includes p-type impurities as the source layer **60** and functions as a part of the source layer **60**. Therefore, the source layer **60** and the diffusion layer **65** are also collectively referred to as the source layers **60** and **65**. Characteristics of the TFET **200** are not influenced even when the diffusion layer **65** is not provided. Other configurations of the second embodiment may be similar to corresponding configurations of the first embodiment.

According to the second embodiment, impurity concentration profiles of the source layer **60** and the channel portion CH are substantially even and smooth. Also in the TFET **200** according to the second embodiment, the area of the channel portion CH (the channel length×the channel width) can be adjusted by adjusting the area of the gate electrode **40** (the gate length×the gate width). Therefore, the second embodiment can achieve effects identical to those of the first embodiment.

Furthermore, the low concentration layer **80** is inserted between the source layer **60** (the channel portion CH) and the drain layer **50**. Therefore, according to the second embodiment, a junction leakage (an off-leakage) and a GIDL current can be further reduced. Accordingly, the second embodiment can further reduce the power consumption.

FIGS. **10**A to **11**B are cross-sectional views showing an example of a manufacturing method of the TFET **200** according to the second embodiment.

After the steps shown in FIGS. **5**A to **6**B have been performed, the source layer **60** is covered with the photoresist **49** using the lithographic technique as shown in FIG. **10**A. A part of the semiconductor layer **20** on the drain side is etched from the surface to a depth not reaching the bottom surface by the RIE method using the photoresist **49** as a mask.

After the photoresist **49** is removed, non-doped silicon is selectively and epitaxially grown on a drain region and a source region. In this way, a monocrystalline layer **95** is formed on the drain region and the source region as shown in FIG. **10**B. The upper surface and the side surfaces of the gate electrode **40** are covered with the hard mask **45** and the spacer **47**. Accordingly, the monocrystalline layer **95** is not in contact with the gate electrode **40**. The monocrystalline layer **95** formed on the drain region becomes the low concentration layer **80** after subsequent steps. The monocrystalline layer **95** on the source layer **60** becomes the diffusion layer **65** after subsequent steps.

A hard mask using an insulating film can be used instead of the photoresist **49**. In this case, when the monocrystalline layer **95** is to be epitaxially grown, the hard mask is kept remained. Accordingly, the monocrystalline layer **95** can be formed on the drain region without formed on the source layer **60**. That is, the monocrystalline layer **95** can be selectively grown on the drain region.

An insulating film such as a TEOS is then deposited on the spacer **47** and the hard mask **45** using the CVD method. The insulating film is then anisotropically etched using the RIE method. Thereby, the side wall film **57** is left on side surfaces of the spacer **47** as shown in FIG. **11**A. In this way, the spacer **47** and the side wall film **57** are formed on the side surfaces of the gate electrode **40**.

The source layer **60** is then covered with the photoresist **59** using the lithographic technique. Ions of n-type impurities (phosphorus or arsenic, for example) are implanted in a part of the semiconductor layer **20** on the drain side using the photoresist **59** as a mask. Activation annealing is then performed using the RTA method, or the like. In this way, the drain layer **50** is formed and the monocrystalline layer **95** on the drain and source regions become the low concentration layer **80** and the diffusion layer **65**, respectively, as shown in FIG. **11**A. For example, phosphorus or arsenic is introduced into the drain layer **50**. Boron is introduced into the source layer **60**. Boron diffuses more easily than phosphorus or arsenic, and thus the diffusion layer **65** can have an impurity concentration almost similar to that of the source layer **60** because of annealing. On the other hand, the low concentration layer **80** is subject to diffusion of the n-type impurities from the high-concentration drain layer **50** and is subject to diffusion of the p-type impurities from the source layer **60**. Therefore, in the low concentration layer **80**, a pn junction is formed in a low-concentration n-semiconductor layer or a low-concentration p-semiconductor layer due to the annealing. Alternatively, the low concentration layer **80** includes an intrinsic semiconductor layer.

After the photoresist **59** is removed, the hard mask **45** is removed using wet etching. Metal such as Ni, Co, or Ti is then deposited on the gate electrode **40**, the diffusion layer **65** (or the source layer **60**), and the drain layer **50** using the PVD method. By reacting the metal with silicon, the silicide layer **70** is formed on the gate electrode **40**, the diffusion layer **65** (or the source layer **60**), and the drain layer **50** as shown in FIG. **11**B.

The interlayer dielectric film **90**, contacts (not shown), metal interconnections (not shown), and the like are then formed to complete the TFET **200** shown in FIG. **9**. While the n-TFET is explained in the second embodiment, a p-TFET can be easily formed by changing the conductivity type of the impurities.

As described above, in the second embodiment, the low concentration layer **80** (an intrinsic semiconductor layer, for example) can be formed between the source layer **60** (the channel portion CH) and the drain layer **50**. Therefore, the junction leakage (the off-leakage) can be further reduced according to the second embodiment.

Third Embodiment

FIG. **12** is a cross-sectional view showing an example of a configuration of a TFET **300** according to a third embodiment. The TFET **300** according to the third embodiment is formed on a bulk semiconductor substrate **12**. In the third embodiment, the semiconductor layer **20** is formed on the surface of the bulk semiconductor substrate **12**. The bulk semiconductor substrate **12** can be, for example, a bulk silicon substrate or a bulk SiGe substrate. The semiconductor layer **20** can be either a silicon layer or a SiGe layer formed on a bulk silicon substrate, or a silicon layer or a SiGe layer formed on a bulk SiGe substrate. Other configurations of the third embodiment may be similar to corresponding configurations of the first embodiment. Therefore, the third embodiment can achieve effects identical to those of the first embodiment.

A manufacturing method of the TFET **300** having a SiGe layer formed on a bulk silicon substrate as the semiconductor layer **20** is explained below.

FIGS. **13**A and **13**B are cross-sectional views showing an example of a manufacturing method of the TFET **300** according to the third embodiment. For example, a $Si_{1-x}Ge_x$ layer **20** is epitaxially grown on the bulk silicon substrate **12** as shown in FIG. **13**A. In this case, x is a positive number. $Si_{1-x}Ge_x$ is a material in which BTBT occurs more easily than in silicon.

The gate dielectric film **30** is then formed on the $Si_{1-x}Ge_x$ layer **20**. Then, the source layer **60** and the channel portion CH are formed by ion implantation as shown in FIG. **13**B.

Thereafter, the steps shown in FIGS. **6**A to **8** are performed to complete the TFET **300**. According to the third embodiment, because the bulk semiconductor substrate is used, the TFET **300** can be easily mounted with a conventional CMOS. In addition, the third embodiment can achieve effects identical to those of the first embodiment.

Needless to mention, the third embodiment can be combined with the second embodiment. That is, the TFET **200** according to the second embodiment can be formed on the bulk semiconductor substrate **12** according to the third embodiment. Therefore, the third embodiment can achieve effects identical to those of the second embodiment.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

The invention claimed is:

1. A semiconductor device comprising:

a semiconductor layer;

a gate dielectric film provided on a surface of the semiconductor layer;

a gate electrode provided on the semiconductor layer via the gate dielectric film;

a drain layer of a first conductivity type provided in a part of the semiconductor layer on a side of a first end of the gate electrode; and

a source layer of a second conductivity type provided in a part of the semiconductor layer on a side of a second end of the gate electrode and below the gate electrode, the source layer having a substantially uniform impurity concentration at the part of the semiconductor layer below the gate electrode,

wherein voltages of a same polarity are applied to the gate electrode and the drain layer.

2. The device of claim **1**, wherein an impurity concentration of a channel portion below the gate electrode is substantially equal to that of the source layer.

3. The device of claim **1**, wherein the source layer extends at least to a region of the semiconductor layer near the side of the first end of the gate electrode and below the gate electrode.

4. The device of claim **1**, wherein the source layer joins the drain layer in a region of the semiconductor layer on the side of the first end of the gate electrode.

5. The device of claim **1**, wherein the source layer joins a low concentration layer having an impurity concentration lower than those of the source layer and the drain layer in the region of the semiconductor layer on the side of the first end of the gate electrode.

6. The device of claim **1**, wherein a reverse bias voltage is applied between the source layer and the drain layer.

7. The device of claim **1**, wherein the semiconductor layer is an SOI layer.

8. The device of claim **1**, wherein the semiconductor layer is a surface layer of a bulk semiconductor substrate.

9. The device of claim **8**, wherein:

the bulk semiconductor substrate is a silicon substrate, and the semiconductor layer is formed using SiGe.

10. A semiconductor device comprising:

a semiconductor layer;

a gate dielectric film provided on a surface of the semiconductor layer;

a gate electrode provided on the gate dielectric film;

a drain layer of a first conductivity type provided in a part of the semiconductor layer on a side of a first end of the gate electrode;

an extension layer of the first conductivity type provided on a surface of the semiconductor layer so as to extend from the drain layer to a part of the semiconductor layer below the gate electrode; and

a source layer of a second conductivity type provided in a part of the semiconductor layer on a side of a second end of the gate electrode and below the gate electrode,

wherein the source layer is provided from the side of the second end of the gate electrode to the part of the semiconductor layer below the gate electrode so as to join the extension layer near the first end of the gate electrode.

11. The device of claim **10**, wherein an impurity concentration of a channel portion below the gate electrode is substantially equal to that of the source layer.

12. The device of claim **10**, wherein the source layer extends at least to a region of the semiconductor layer near the side of the first end of the gate electrode and below the gate electrode.

13. The device of claim **10**, wherein a reverse bias voltage is applied between the source layer and the drain layer.

14. The device of claim **10**, wherein the semiconductor layer is an SOI layer.

15. The device of claim **10**, wherein the semiconductor layer is a surface layer of a bulk semiconductor substrate.

16. The device of claim **15**, wherein:

the bulk semiconductor substrate is a silicon substrate, and the semiconductor layer is formed using SiGe.

17. A semiconductor device comprising:

a semiconductor layer;

a gate dielectric film provided on a surface of the semiconductor layer;

a gate electrode provided on the semiconductor layer via the gate dielectric film;

a drain layer of a first conductivity type provided in a part of the semiconductor layer on a side of a first end of the gate electrode;

a source layer of a second conductivity type provided in a part of the semiconductor layer on a side of a second end of the gate electrode and below the gate electrode; and

a low concentration layer provided in a part of the semiconductor layer between the source layer and the drain layer, the low concentration layer having an impurity concentration lower than those of the source layer and the drain layer,

wherein the source layer is provided from the side of the second end of the gate electrode to the part of the semiconductor layer below the gate electrode so as to join the low concentration layer near the first end of the gate electrode.

18. The device of claim **17**, wherein an impurity concentration of a channel portion below the gate electrode is substantially equal to that of the source layer.

19. The device of claim **17**, wherein the source layer extends at least to a region of the semiconductor layer near the side of the first end of the gate electrode and below the gate electrode.

20. The device of claim **17**, wherein a reverse bias voltage is applied between the source layer and the drain layer.

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